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CALCULUS OF VARIATIONS AND THE LOGISTIC CURVE

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I HAVE been able to show that the equations of the struggle for existence depend on a question of Calculus of Variations, or more precisely on a problem of minimum.

In order to obtain this result, I have replaced the notion of *population* by that of *quantity of life*.[1] In this manner I have also obtained some results by which dynamics is brought into relation to problems of the struggle for existence.

2. The quantity of life X and the population N of a species are connected by the relations

$$X = \int_0^t N dt \quad , \quad N = \frac{dX}{dt}$$

where N is to be considered as a function of the time. All depends on a theorem of Calculus of Variations that I have already used in my memoir above cited. I shall now give the enunciation, the demonstration, and some applications of this theorem.

[1] Principes de Biologie Mathématique: Ière Partie. §1 N. 2. *Acta Biotheoretica*, Vol. 3, Pars 1, 1937.

3. THEOREM: *The differential equation*

$$\frac{dz}{dt} = f(z) = a(z-a_1)\,(z-a_2)\,\ldots\ldots\,(z-a_n) \qquad \text{(i)}$$

where $f(z)$ is a rational and integral polynomial of degree n can be obtained by equating to zero the first variation of

$$P = \int_o^T F(t)dt\,,\; F = \sum_1^n m_i\left(a_i - \frac{dX}{dt}\right)\log\left(a_i - \frac{dX}{dt}\right) + KX$$

and by making a convenient choice of the constants m_i, K.

In fact we shall have

$$\delta P = \int_o^T \delta F dt = \int_o^T \left\{ -\Sigma_i m_i \frac{d\delta X}{dt} \log\left(a_i - \frac{dX}{dt}\right) - m_i \frac{d\delta X}{dt} + K\delta X \right\} dt \qquad \text{(ii)}$$

and with an integration by parts, neglecting the terms out of the integral, this takes the form

$$\delta P = \int_o^T \delta X \left[\Sigma_i \frac{-m_i \dfrac{d^2X}{dt^2}}{a_i - \dfrac{dX}{dt}} + K \right] dt. \qquad \text{(iii)}$$

If $\delta P = 0$ for every value of δX then we shall have

$$\Sigma_i \frac{m_i \dfrac{d^2X}{dt^2}}{a_i - \dfrac{dX}{dt}} = K,$$

from which we deduce, by putting $\dfrac{dX}{dt} = z$,

$$Q(z)\,\frac{dz}{dt} = K(a_1 - z)\,(a_2 - z)\,\ldots\,(a_n - z), \qquad \text{(iv)}$$

4. $Q(z)$ is a polynomial of degree $n-1$ linear and homogeneous with respect to $m_1, m_2, \ldots m_n$.

We can write

$$Q(z) = A_1 z^{n-1} + A_2 z^{n-2} + \ldots\ldots A_n \qquad \text{(v)}$$

where

$$A_i = m_1 p_{1i} + m_2 p_{2i} + \ldots\ldots + m_n p_{ni} ,$$

A_i and $p_{1i}, p_{2i} \ldots\ldots p_{ni}$ being of degree $i-1$ with respect to $a_1, a_2, \ldots\ldots a_n$.

If we write

$$A_1 = A_2 = \ldots\ldots = A_{n-1} = 0 \qquad A_n = A \qquad \text{(vi)}$$

(A constant) we have n equations linear and homogeneous with respect to $m_1, m_2, \ldots\ldots m_n$.

The determinant of these equations is

$$D = \begin{vmatrix} p_{1\,1}, & p_{1\,2}, \ldots\ldots & p_{1\,n} \\ p_{2\,1}, & p_{2\,2}, & p_{2\,n} \\ \cdots\cdots & \cdots\cdots & \cdots\cdots \\ p_{n\,1}, & p_{n\,2}, & p_{n\,n} \end{vmatrix} .$$

Considering that $p_{1i}, p_{2i}, \ldots\ldots p_{ni}$ are of degree $i-1$ with respect to $a_1, a_2, \ldots\ldots a_n$ we shall see that D is of degree

$$1 + 2 + \ldots\ldots + (n-1) = \frac{n(n-1)}{2} .$$

Moreover by changing i with s we produce an exchange between the columns i and s; hence D admits the factors $a_i - a_s$. They are in number of $\frac{n(n-1)}{2}$. We conclude that D will be equal to a constant multiplied by all the factors $a_i - a_s$, which can be obtained by means of the combinations two by two of the indexes $1, 2, \ldots\ldots n$. Hence D will not be zero if $a_1, a_2, \ldots\ldots a_n$ are all different among them.

Therefore we can determine $m_1, m_2, \ldots\ldots m_n$ as solutions of equations (vi). Then we have $Q(z) = A$ and

$$\frac{dz}{dt} = a(a_1 - z)(a_2 - z) \ldots\ldots (a_n - z)$$

where

$$a = \frac{K}{A^n} .$$

5. We have demonstrated the theorem in the case where $f(z)$ does not have multiple roots. The case of multiple roots can be treated by the usual procedure supposing that two or more roots become indefinitely near among them.

We shall consider only a particular example. Let us suppose a case having three roots and that $a_2 = a_3$.

We can write

$$F = m_1\left(a_1 - \frac{dX}{dt}\right)\log\left(a_1 - \frac{dX}{dt}\right) + m_2\left(a_2 - \frac{dX}{dt}\right)\log\left(a_2 - \frac{dX}{dt}\right) + \frac{m_3}{\epsilon}\left[\left(a_2 + \epsilon - \frac{dX}{dt}\right)\log\left(a_2 + \epsilon - \frac{dX}{dt}\right) - \left(a_2 - \frac{dX}{dt}\right)\log\left(a_2 - \frac{dX}{dt}\right)\right]. \quad \text{(vii)}$$

As ϵ approaches zero, F approaches

$$m_1\left(a_1 - \frac{dX}{dt}\right)\log\left(a_1 - \frac{dX}{dt}\right) + m_2\left(a_2 - \frac{dX}{dt}\right)\log\left(a_2 - \frac{dX}{dt}\right) + m_3\log\left(a_2 - \frac{dX}{dt}\right) + m_3,$$

and if we take $\delta P = 0$ we shall obtain the equations

$$m_1a_2^2 + m_2a_1a_2 + m_3a_1 = A \quad \text{(viii)}$$

$$2m_1a_2 + m_2(a_1 + a_2) + m_3 = 0 \quad \text{(ix)}$$

$$m_1 + m_2 = 0 \quad \text{(x)}$$

whose determinant D is $-(a_1 - a_2)^2$, and therefore is not zero if

$$a_1 \gtrless a_2.$$

6. Starting from the expression (ii) for δP we obtain for the second variation

$$\int_0^T \Sigma_i \frac{m_i\left(\frac{d\delta X}{dt}\right)^2}{a_1 - \frac{dX}{dt}}\,dt.$$

If $m_i > 0$ and $a_i > \frac{dX}{dt}$ $(i = 1, 2 \ldots . n)$ the preceding expression is positive and then we shall have a minimum.

7. In a lecture published in 1937[2] I spoke about the variational principle in mathematical biology. Having received that memoir, Prof.

[2] Enseignement Mathématique, Vol. 30:6.

L. Amoroso asked me this question: Is it possible to reduce the equation of Verhulst-Pearl to the Eulerian form in the sense indicated in my memoir and to reduce consequently the movement of human population to a principle of minimum?

I have been able to answer this interesting question by means of the preceding theorem showing that it is also applicable to the Verhulst-Pearl case.

8. In fact the Verhulst-Pearl differential equation can be written

$$\frac{dN}{dt} = N(\epsilon - \lambda N).$$

Now let us proceed as in Section 2 above. Letting

$$N = \frac{dX}{dt}$$

the integral whose variation we must consider can be written

$$\int_0^T \left(m_1 \frac{dX}{dt} \log \frac{dX}{dt} + m_2 \left(\epsilon - \lambda \frac{dX}{dt} \right) \log \left(\epsilon - \lambda \frac{dX}{dt} \right) + KX \right) dt$$

and its first variation will be

$$\int_0^T \left[\left\{ m_1 \log \frac{dX}{dt} + m_1 - m_2 \lambda \log \left(\epsilon - \lambda \frac{dX}{dt} \right) - m_2 \lambda \right\} \frac{d\delta X}{dt} + K \delta X \right] dt. \qquad \text{(xi)}$$

Integrating by parts and neglecting the terms out of the integral we shall have

$$\int_0^T \left[\left(- \frac{m_1}{\frac{dX}{dt}} - \frac{m_2 \lambda^2}{\epsilon - \lambda \frac{dX}{dt}} \right) \frac{d^2X}{dt^2} + K \right] \delta X dt.$$

Equating to zero this first variation and letting $m_1 = \lambda m_2$ we reach the equation

$$\frac{d^2X}{dt^2} = h \frac{dX}{dt} \left(\epsilon - \lambda \frac{dX}{dt} \right) \qquad (h \text{ constant}) \qquad \text{(xii)}$$

that is

$$\frac{dN}{dt} = hN(\epsilon - \lambda N), \qquad \text{(xiii)}$$

which is Pearl's equation.

If we calculate the second variation starting from equation (xi) we find

$$\int^{T}\left(\frac{m_1\left(\frac{d\delta X}{dt}\right)^2}{\frac{dX}{dt}}+\frac{m_2\lambda^2\left(\frac{d\delta X}{dt}\right)^2}{\epsilon-\lambda\frac{dX}{dt}}\right)dt. \qquad \text{(xiv)}$$

Now since

$$0<\frac{dX}{dt}=N<\frac{\epsilon}{\lambda}$$

we can say that the second variation is positive and hence that we have a minimum.

9. In a preceding paper[3] I have extended Pearl's equation, taking into account beside the *mortality term* and *Pearl's term* also a *birth term*; I have thus found an equation [See § 8 equation (i')[3]] which can be written in the form (i). Therefore the theorem enunciated in Section 2 of the present paper is applicable to the cases treated in the earlier paper[3] above mentioned.

(I am very grateful to Miss H. Freda for translating this paper.)

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[3] Volterra, Vito. 1938. Population growth, equilibria, and extinction under specified breeding conditions: A development and extension of the theory of the logistic curve. HUMAN BIOLOGY, Vol. 10, pp. 1-11.

AUTOSOMAL LINKAGE BETWEEN THE FACTORS FOR THE PRODUCTION OF IDENTICAL AND OF FRATERNAL TWINNING

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INTRODUCTION

IT HAS been shown by Curtius[1] that like-sexed fraternal and identical twins do occur in the same families and sometimes in the same fraternities, while Dahlberg[2] has shown that a marked excess of like-sexed twins occurs both among the offspring of mothers who had previously produced an unlike-sexed pair of twins, and among the offspring of mothers who had previously produced a like-sexed pair of twins. These observations, when taken in conjunction with those of Southwick[3] could be considered to indicate that the factors for the production of identical and those for the production of fraternal twinning tend to occur together in the same kindred* with a significantly high degree of regularity. For these reasons, it is believed that these factors are associated in some way, and this study was undertaken in order to determine the nature of this association.

MATERIALS AND METHODS

The study was conducted upon all of the kindreds containing four or more twins which were filed under Trait 053 and 053S in the "A"

[1] Curtius, F. Über erbliche Beziehungen zwischen eineiigen und zweieiigen Zwillingen und die Zwillingsvererbung im allgemeinen. *Ztschr. f. Konstit.*, 1927, Bd. 13, S. 286-317.

[2] Dahlberg, G. Über die Vererbung der Neigung zu Zwillingsschwangerschaft und über potentielle Fruchtbarkeit im Lichte einer Theorie der Polyovulation beim Menschen. *Ztschr. Geburtsh.*, 1930, Bd. 99, S. 136-176.

[3] Southwick, W. E. Sex ratios and twin producing kindreds. *Am. Nat.*, 1939, Vol. 73, pp. 44-68.

* A kindred is defined as "a group of persons, all members of which are related, either by direct kinship relationship or by marriage, to every other member, but, in so far as can be known at any given time from the available records or otherwise, to no other person or persons".

File of the Eugenics Record Office. It was believed that kindreds containing a smaller number of twins would not provide sufficient data to allow one to determine the nature of the condition. Otherwise, the data of the archives were left unselected, for it seemed that such unselected data could be considered to represent a random collection of identical and fraternal twins in their typical and various relationships.

There were, in all, 140 kindreds which had four or more twins, and these contained a total of 1,131 twins. Twins of unknown sex, triplets, and quadruplets were ignored in selecting these kindreds. Of the twins in these kindreds, 403 pairs were of unlike sex while 728 were of like sex. According to the difference method of Weinberg[4] for calculating the number of identical and fraternal twins, one may determine that there are $1131 - 806 = 325$ identical twins, or 28.73 per cent. This is essentially in agreement with the values obtained by numerous other observers on similar data, the most recent of which is that of 26 per cent cited by Newman[5] based on a twin population of 717,907 twin pairs as provided by J. B. Nichols. The figures of this study also give a percentage of 64.37 per cent like-sexed twins to 35.63 per cent unlike-sexed twins for the total population. The figures for the percentage of like-sexed twins in the population will be used in this study, hereafter, in preference to those for per cent of "identical" twins.

It is obvious that the occurrence of any association between the factors for the production of identical and those for the production of fraternal twinning, such as has been indicated by Curtius and Dahlberg, and such as has been clearly demonstrated by the earlier studies on material at the Eugenics Record Office, must be produced in one of two general ways. Either the underlying factor or factors must take the form of a single genic condition — which, however, might act, on the one hand, directly to produce the two phenotypic conditions, or, on the other hand, indirectly, by the direct production of a single phenotypic condition, which, in its turn, might produce the two conditions — or, the underlying factor or factors must take the form of two distinct but genetically linked genes. Environmental factors might or might not markedly influence the operation of either of these two mechanisms.

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[4] Weinberg, W. Beiträge zur Physiologie und Pathologie der Mehrlingsgeburten beim Menschen. *Archiv. f. d. gesammte Physiologie,* 1901, Bd. 88, S. 346-430.

[5] Newman, H. H., Freeman, F. N., and Holzinger, K. J. Twins. A Study of Heredity and Environment. *Chicago, Ill.,* The Univ. of Chicago Press, 1937.

If the association were due, accordingly, to but a single genic condition, then the characteristic identificatory nature of such a gene would be that it establish conditions such that the like- and unlike-sexed twins would occur in the ratio, as already determined for this population, of 64.37 per cent. If, furthermore, the determination of this ratio were based, not on the gross statistical summation of all the twins, but rather on the ratios or percentages of like-sexed twins which occurred in the smaller groups of twins (either within the kindreds or in the different kindreds) then the 64.37 per cent would represent, in the case of a single, genic, fundamental condition, the mean of a unimodal frequency distribution.

The usual factors that produce biological variation in general would, of course, produce the major variations which would occur in such a series of determinations, but the degree of such variation might be further determined by the number of distinct types of factors which might be operative in the production of the final condition and the nature and extent of such variations might be diagnostically indicative of the mode of action of the single genic condition. Thus, a small standard deviation might be considered to indicate the direct action of the single gene in the production of the two phenotypic conditions, a moderate standard deviation could indicate the indirect action of the single gene, probably by the production of a single phenotypic character which in its turn would produce the two conditions, while a large standard deviation would indicate the influence also of environmental conditions.

On the other hand, if the association were due to two distinct, but genetically linked genes, the characteristic identificatory nature of such a condition would be that each gene would act independently to establish conditions such that both the dizygotic and monozygotic twins would occur, independently and each with its characteristic frequency. Linkage, as is well known from the many experiments of Bridges[6] and others, is detected by means of the occurrence of crossing over between the two gene loci, while the distances between two genes is indicated, as shown on the linkage maps of Bridges[6] by the amount of such crossing over. The positive demonstration, therefore, of crossing over phenomena in relation to the occurrence of these two types of twinning would constitute definite evidence that the factors for the production of the

[6] Bridges, C. B. A revised map of the salivary gland X-chromosome of *Drosophila melanogaster*. *Jour. of Heredity*, 1938, Vol. 29, pp. 11-13.

two types of twinning would be in the nature of two genetically linked genes.

On the basis of the postulated occurrences of such crossing over, therefore, one would expect to find some chromosomes which would bear the genes both for monozygotic twinning and for dizygotic twinning, some which would bear the gene for monozygotic twinning with the normal allelomorph of the gene for dizygotic twinning, others which would bear the gene for dizygotic twinning with the normal allelomorph of the other gene and, of course, chromosomes which would bear only the normal allelomorphs of the gene for each type of twinning. By definition of these genes, therefore, the kindreds, or portions of kindreds, which contain the chromosomes that bear genes for both types of twinning, would produce like- and unlike-sexed twins in ratios such that the frequency distribution of the percentage determinations of like-sexed twins, made on the basis of the small groups of twins within the kindreds, or in the different kindreds, would have a mode at approximately 64.37 per cent. On the other hand, the kindreds which contain only the chromosomes that bear the gene for monozygotic twinning would produce only like-sexed twins, while the kindreds which contain chromosomes that only bear the gene for dizygotic twinning would produce like- and unlike-sexed twins in ratios such that the frequency distribution of the percentage determinations of like-sexed twins, as already described, would have a mode at approximately 50 per cent.

If such cross-over chromosomes should occur among the kindreds considered in this study, then it would follow, on the basis of the foregoing discussion, that the distribution curve for the percentages of like-sexed twins would be tri-modal in nature with one mode centering at approximately 64.37 per cent, one at approximately 50 per cent, and one exactly at 100 per cent. It should be possible to determine, therefore, of the two possible conditions which one has actually occurred, by means of making a determination and study of the distribution curves for the percentages of like-sexed twins which have occurred in the small groups within and among the kindreds, as already explained.

In order to obtain a highly exact and representative determination of these small groups within the kindreds, the significant portions of the original data, as filed in the archives, were transcribed onto ordinary cross-section paper. In order to facilitate and expedite this work, a system of recording was devised, which is shown in Figure 1,a. A

a. Diagram to show the method used for concisely recording the kinship relationships between the twin producing individuals.

(F F)(F F)(F M M)(M U)(U F M)(M(F)(U F F)(M F)(M)(U F)(U U M)(U M F)(M)(M F U)(U U)
2 0 2 3 3 4 1 1 5 3 3 4 4 3 3
Indicator Groups

[F F F F M M][M U U F M F U F F M F M][U F U U M U M F M M F U U U]
100 70 46.15
Percentage Determination Units

b. Symbols showing the formation of the indicator groups, and the percentage determination units. These are to be compared with the diagram appearing in a.

FIG. 1. A DIAGRAM TO DEMONSTRATE THE METHOD USED FOR RECORDING THE KINSHIP RELATIONSHIPS BETWEEN TWIN-PRODUCING INDIVIDUALS, DESIGNED TO FACILITATE THE DETERMINATION OF THE INDICATOR GROUPS AND OF THE PERCENTAGE DETERMINATION UNITS.

Explanation of Symbols

X = twin; |F = female ancestor of twin; |M = male ancestor of twin; F = like-sexed female twins; M = like-sexed male twins; U = unlike-sexed twins; ( )' = maximum degree of kinship in the group; ( ) = indicator group; [ ] = percentage determination unit; 70 = percentage of like-sexed twins in unit.

cross (X) represents the occurrence of a twin, the type of which is represented vertically below the cross by means of symbols, as explained in the figure. Vertical coordinates represent ancestral and descendant generations, one unit to a generation, while the horizontal coordinates represent collateral kinship relationships. Only one twin is represented in a vertical column. Each unbroken horizontal line represents one sibship. The sex of the person in direct line of relationship is indicated by means of symbols placed to the right of the person represented. Parents appear in different vertical columns. The purpose of this system was solely to represent the kinship relationships between twin producing individuals, so no attempt was made to represent individuals who were not in a direct line of relationship between the twins. The kinship relationships of the 1,131 twins in the 140 kindreds used in this study were represented in this way. Figure 1,a represents a typical kindred of this group.

Having the kinship relationships of the twins diagramatically expressed in this way, it was comparatively simple to determine the various groupings. This was done in accordance with certain very definite conditions which were established in advance. The "degree of relationship" between the twin producing individuals was determined by counting the number of the coordinate units that occurred between the various twins. Each unit ancestrally or descendantly counted as one unit of kinship, and each sibship counted as one unit. The numbers that were obtained in this manner provided a ready and simple method for obtaining a rough index which would indicate the relative closeness of the kinship relationship between the two twin producing individuals. The smaller numbers indicated the closer kinship relationships.

In this study, an attempt was made to maintain an average degree of kinship of three degrees, as already explained, for the groups within one kindred, while, in no case, were more than five degrees of kinship allowed for any group. Once these groups within the kindreds had been determined with the aid of the index, the degree of kinship number was ignored, and all groups were considered to be of equivalent significance. The slight variations about a mean of three did not seem to require detailed and specific consideration.

An attempt was made to maintain two or three twins as the usual size for the groups. Groups of four occurred quite frequently, but these, and the larger groups, were considered superfluous and so were subdivided into groups of two or three twins. The selection of these

groups on the basis of such considerations was completely determined by the prearranged conditions, and essentially the same groupings would be obtained by any operator acting in accordance with such conditions.

The groupings were represented symbolically as shown and explained in Figure 1,b. The groups were designated by means of parentheses drawn around the corresponding twin symbols, and the maximal degree of kinship occurring within the group was represented in the exponential position of the parenthesis. The size of the group was represented, of course, by the number of twin symbols that appeared within the parenthesis. The same kindred was used for Figure 1,a and Figure 1,b, so that comparisons might readily be made.

By dividing each kindred into groups in this way, each group would become, in essence, an indicator, such that it might well be termed an "indicator group". With a series of such indicator groups, the nature of the underlying genetic configuration of a twin producing kindred could be regularly determined, and, in a collection of kindreds where the two twinning tendencies were associated in some way, a clear indication of the quantitative degree of that condition could be regularly obtained. These series of indicator groups have been termed "percentage determination units", and contain, usually, from one to ten such groups. In this study, only kindreds that contained three or more indicator groups appeared to be of sufficient size to allow for the making of reliable determinations of the ratios.

ANALYSIS

In the total of 140 kindreds used in this study, 41 provided an opportunity to study the results when 3 or more indicator groups were contained within one kindred. These 41 kindreds provided a total of 267 groups and represented a total of 621 twins. The percentage of like-sexed twins was 62.96 per cent, or reasonably close to the 64.37 per cent that was obtained for the whole population. In order to facilitate the further analysis of this collection of the data, the kindreds were divided into two subdivisions. One considered the data from kindreds that contained less than eight indicator groups, while the other division concerned the data of the remaining kindreds.

In the data from the collection of the smaller kindreds the determinations of the percentages of like-sexed twins were made separately for the three twin groups and for the two twin groups that occurred within each kindred. There were, in this collection of data, 47 such determina-

TABLE 1

The number of like- and of unlike-sexed twins that occur in the groups of 1, 2, and 3 twin and the percent of like-sexed twins in the percentage determination units for all the kindreds that contain from 3 to 7 indicator groups

KINDRED NUMBER AND "A" FILE REFERENCE	NUMBER OF TWIN PAIRS						PERCENT OF LIKE-SEXED TWINS			
	Groups of three twin pairs		Groups of two twin pairs		Groups of one twin pairs		Groups of Three Twins		Groups of Two Twin	
	Like-Sexed	Unlike-Sexed	Like-Sexed	Unlike-Sexed	Like-Sexed	Unlike-Sexed		#		#
39.165-173	4	2	6	2	.	1	66.67	62.5	75	80
73	3	3	4	2	.	.	50	..	66.67	..
75	3	.	6	.	1	.	100	..	100	..
78-79	.	.	3	3	.	1	..	..	50	..
105	.	.	6	.	.	.	..	..	100	..
120-121	3	.	3	1	.	.	100	..	75	..
131	4	2	.	2	.	.	66.67	100	0	20
141-142	1	2	2	4	.	.	33.33	..	33.33	..
189-191	3	.	5	1	.	.	100	100	83.33	75
197	3	.	3	1	.	.	100	..	75	..
275-278	.	.	6	.	.	.	..	..	100	..
279-283	.	.	3	3	.	.	..	..	50	..
407-414	3	3	4	2	3	.	50	40	66.67	71
415-424	3	3	5	3	2	.	50	..	62.5	..
447-451	2	1	1	3	2	1	66.67	..	25	..
452-459	3	3	1	1	1	1	50	..	50	..
507-511	4	2	5	3	1	.	66.67	62.5	62.5	66
539-542	2	1	3	3	.	.	66.67	75	50	40
702	.	.	5	1	.	.	..	..	83.33	..
740-741	.	.	3	3	.	.	..	..	50	..
791-793	1	2	1	3	.	.	33.33	..	25	..
513-515 S	.	.	4	2	.	.	..	..	66.67	..
627-627bS	.	.	4	2	.	.	..	..	66.67	..
631-631bS	.	.	5	1	.	.	..	..	83.33	..
632-632bS	.	.	6	.	.	.	..	..	100	..
636-636aS	2	1	7	1	.	.	66.67	100	87.5	60
644 S	.	.	5	3	.	.	..	..	62.5	..
712aS	2	4	2	2	.	.	33.33	60	50	20
909-909bS	3	.	2	2	.	.	100	..	50	..
Totals	52	32	107	51	10	4	..	..	..	..
Total number of kindreds										29
Total number of twins										251

The numbers in these columns are the determinations based on units composed of groups that were more closely related than the groups that composed the units based on "all of the three twin groups", or "all of the two twin groups" of the kindred.

tions and the values are shown in Table 1. In twenty-one of these kindreds, these units represented also the combinations of the most closely related indicator groups. In the remaining eight kindreds, percentage determination units could be obtained by combining the more closely related groups, and the values obtained from these units are given to the right of the percentages determined on the other basis. These values have been used for subsequent calculations. The small size of these kindreds rendered impracticable any more involved criteria for obtaining the percentage determination units.

An examination of Table 1 shows that there were in all eleven determinations of 100 per cent, and eight determinations of 50 per cent. There were, in addition, six determinations in four kindreds, both determinations of which were below 50 per cent or averaged below 50 per cent. From these cases, it is clear that occasionally distinct units of indicator groups do occur in close kinship relationships which have 100 per cent, or approximately 50 per cent, like-sexed twins. On the other hand, the distribution of the other determinations of this collection of kindreds is fairly symmetrical with a mean at 62.07 per cent.

In the subdivision of the kindreds which contained eight or more indicator groups, 351 twins were represented, of which 62.10 per cent were of like sex. In these kindreds, the percentage determination units were, when possible, formed in a way such that the average size would be approximately 10 twin pairs, and the data arranged in this way are presented in Table 2. Ten twin pairs were considered to be adequate for the provision of a reliable percentage determination, and it was desired to have as many such determination units as possible. Thirty-two such units were formed. Only indicator groups, as previously determined, were considered in the formation of these units, and an attempt was made to have these units composed of indicator groups that were as closely related as possible. The exact size of the unit was determined in accordance with this condition, and varied between 7 and 15 twins per unit. In some cases, certain isolated indicator groups were unrelated to a unit, and so were excluded.

From an examination of Table 2, one may see that there were two determinations of 100 per cent, and eleven determinations of approximately 50 per cent or less. The other determination units averaged 66.82 per cent or reasonably close to 64.37 per cent.

It it clear, therefore, that in both of these collections of kindreds, units containing either 100 per cent, or approximately 50 per cent like-

TABLE 2

Composition and percentage of like-sexed twins of each of the percentage determination units in kindreds which contain eight or more indicator groups of twins

KINDRED NUMBER AND "A" FILE REFERENCE	NUMBER OF TWINS PER PERCENTAGE DETERMINATION UNIT			PERCENTAGES OF LIKE-SEXED TWINS	
	Like sex	Unlike sex	Total	Per percentage determination unit	Whole kindred
230	7	-	7	100	--
	7	3	10	70	--
	6	7	13	46.15	66.67
425-432	10	4	14	71.43	--
	4	7	11	36.36	56
433-439	5	5	10	50	--
	10	5	15	66.67	60
440-446	5	7	12	41.67	--
	6	7	13	46.15	44
469-475	9	3	12	75	75
476-483	7	6	13	53.85	--
	9	4	13	69.23	61.5
484-487	5	3	8	62.5	--
	4	7	11	36.36	47.4
488-506	10	-	10	100	--
	6	4	10	60	--
	5	5	10	50	--
	5	3	8	62.5	--
	4	5	9	44.44	63.83
512-536	10	5	15	66.67	--
	8	2	10	80	--
	7	1	8	87.5	--
	8	4	12	66.67	--
	4	7	11	36.36	--
	8	2	10	80	--
	7	5	12	58.33	66.67
712-712kS	9	3	12	75	75
802-810 S	5	3	8	62.5	--
	3	5	8	37.5	50
932-934 S	8	3	11	72.72	--
	7	3	10	70	--
	10	5	15	66.67	69.4

sexed twins do occur. The relative frequency of this occurrence is shown in Figures 2 and 3, where the frequencies of the various percentages of like-sexed twins are presented separately for the units of each size, and separately for the complete set of data, or set "a" and for the set of data from which the 50 and 100 per cent determinations have been excluded, or set "b". The values indicated by these data have been

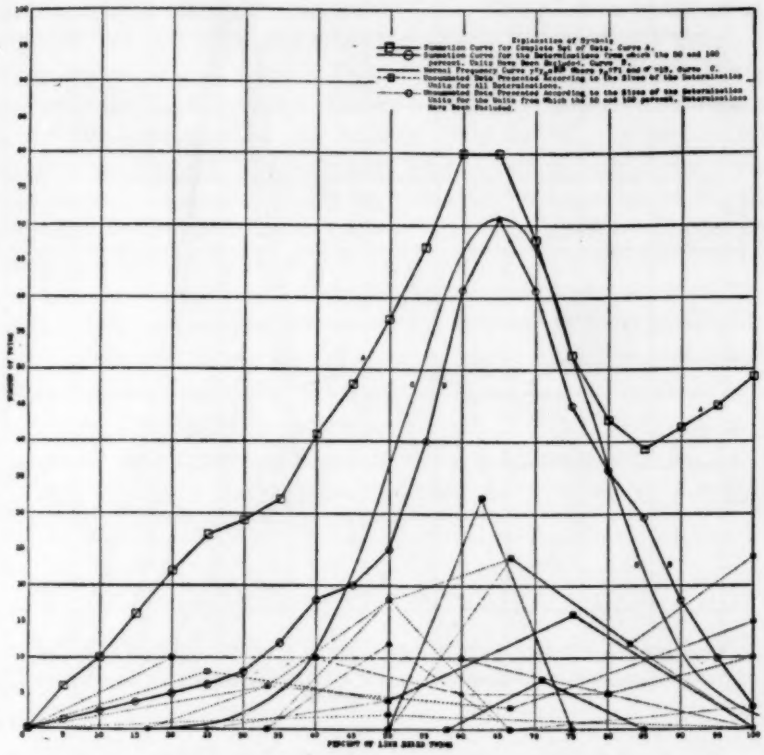

FIG. 2. A FIGURE TO SHOW THE OCCURRENCE OF TWINS, ACCORDING TO THE PERCENTAGE OF LIKE-SEXED TWINS THAT OCCUR IN THE PERCENTAGE DETERMINATION UNITS, PRESENTED BOTH ANALYTICALLY AND IN A SUMMATION CURVE, AND FOR THE COMPLETE SET OF DATA, AND FOR THE DATA FROM WHICH THE 50 AND 100 PERCENT DETERMINATIONS HAVE BEEN EXCLUDED

For comparison, a normal frequency curve is also included. The bimodal nature and asymmetrical lower left hand portion of the summation curve for the complete set of data is clearly marked.

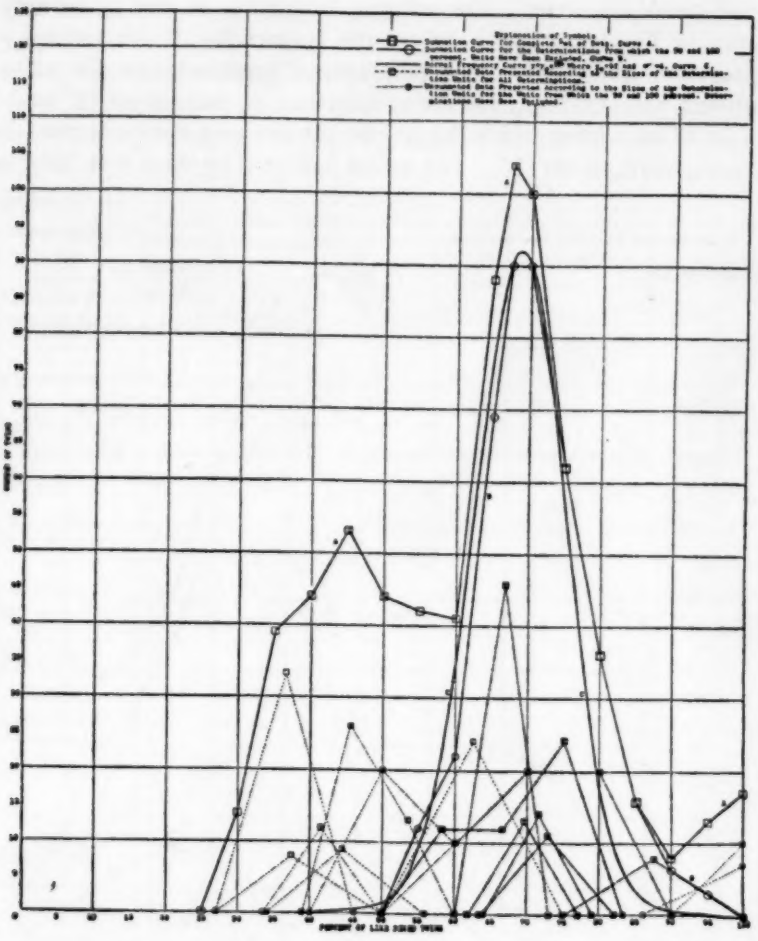

FIG. 3. A FIGURE TO SHOW THE OCCURRENCE OF TWINS, ACCORDING TO THE PERCENTAGE OF LIKE-SEXED TWINS THAT OCCUR IN THE PERCENTAGE DETERMINATION UNITS, PRESENTED BOTH ANALYTICALLY AND IN A SUMMATION CURVE, AND FOR THE COMPLETE SET OF DATA, AND FOR THE DATA FROM WHICH THE 50 AND 100 PERCENT DETERMINATIONS HAVE BEEN EXCLUDED

For comparison, a normal frequency curve is also included. The trimodal nature of the summation curve for the complete set of data is clearly marked.

summated at 5 unit intervals, and the results of this procedure shown by curve "A" for the data of set "a", and by curve "B" for the data of set "b". The percentage of like-sexed twins, determined from the actual data for these two sets of twins, was respectively 65.40 and 62.07 per cent for the smaller kindreds, and 62.10 and 66.82 per cent for the other kindreds.

An examination of Figures 2 and 3 shows that three very distinct modes occur in the summation curve "A". One of these is the normally expected one that occurs at approximately 65 per cent, one occurs definitely at 100 per cent, while in Figure 3 the third occurs at approximately 45 per cent. In Figure 2 a distinct irregularity and asymmetry occurs in the left-hand portion. In both of these curves, the portion which presents the mode at approximately 65 per cent is very symmetrical as may be seen even more clearly by comparing that portion of the curve with the normal distribution curves "C". The portions of the curves which provide the mode at approximately 45 per cent, and exactly at 100 per cent, arise abruptly from the central portion of the curve. These conditions show that distinct percentage determination units of 100 per cent and approximately 50 per cent do occur within the collection of kindreds considered in this study.

On the other hand, the summation curve "B" in both figures may be seen to be quite symmetrical with a mode at approximately 65 per cent, and this symmetry is even more apparent when the curve is compared with the normal distribution curve "C".

DISCUSSION

As has already been explained in detail, when the occurrence of an association between two traits can be demonstrated, as has been done in the case of monozygotic and of dizygotic twinning, it is possible further to determine the nature of the association by determining the consistency with which the two conditions appear together in the kindreds. If the two traits *always* occur together, one might expect that but a single genic condition would be concerned. On the other hand, when the three distinct combinations of (1) both traits together, or (2 and 3) each trait singly, occur, it is possible that two genetically linked genes would be involved. The three combinations represent the various conditions that would result from the two genes crossing over respectively with the corresponding normal allelomorphs.

Since, in the case of twinning, the identification of the type of the twin is accomplished by means of a determination of the percentage of like-sexed twins, the usual statistical variation that is characteristic of many biological systems must be considered in the determination of the genic nature of such traits. In order to do this, it has been necessary to determine the percentage of like-sexed twins for a large number of small groups within and among the kindreds. If but a single genic condition were involved, the values of these percentages would be expected to conform to a simple *unimodal* distribution; whereas, if two genetically linked genes were involved, a trimodal distribution would be expected. Each mode would represent one of the genic combinations already mentioned, and, in the case of monozygotic and dizygotic twinning, would be expected to occur at approximately 50, 65, and at exactly 100 per cent.

An analysis of this sort has been made, and, as may be seen from an examination of Figures 2 and 3, the occurrence of the trimodal type of distribution is clearly and unquestionably demonstrated. In Figure 3 the modes occur at 45, 67.5, and 100 per cent. In Figure 2 modes occur at 62.5 and 100 per cent, while marked distortions of the lower left-hand portion of the curve may readily be discerned by making a comparison with the normal frequency distribution curve "C" shown in that figure. It is necessary to conclude, therefore, on the basis of this data that monozygotic and dizygotic twinning are, in their final and fundamental determination, dependent upon genes which are genetically linked.

That this linkage occurs on an autosomal chromosome is shown by the lack of any sexual pattern in the transmission of the traits, and by the work of Davenport[7] in which it has been shown that both the father and the mother are equally able to cause the production of twins. On this basis it would appear that the genes for the production of twinning are located, not on a sex chromosome, but rather on one of the autosomal chromosomes. If this be true, then it could be concluded that twinning in man is produced by two autosomal genes linked on one chromosome.

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[7] Davenport, C. B. Influence of the male in the production of human twins. *Am. Nat.*, 1920, Vol. 54, pp. 122-129.

———. Heredity of twin births. *Proc. Soc. Exp. Biol. and Med.*, 1920, Vol. 27, pp. 75-77.

———. Influence of the male on the production of twins. *The Medical Record*, 1920.

———. Does the male have an influence in human twin production? *Ztschr. indukt. Abstammgl.*, 1927, Bd. 46, S. 85-86.

The manner of development of the various types of monozygotic and of dizygotic twins, together with some of the underlying genetic mechanisms whereby hereditary factors might operate, have been described in detail in an earlier paper. There is little to be added at this time except to state that the analysis outlined in this paper has definitely demonstrated that, of the various possibilities outlined in the earlier article, the genetic linkage of genes for the two phenotypic characteristics of twinning is the one that has actually occurred.

On this basis, therefore, there is one gene for monozygotic twinning and one for dizygotic twinning. The gene for monozygotic twinning might still be of the nature of a "weak dominance", as explained and developed in detail in the earlier paper. The gene for dizygotic twinning might be of a nature such as to affect the action of the zygote at the time of implantation so that it would not cause the uterus to become unreceptive as rapidly as normally. As suggested in the earlier paper, in a case of this kind, it might frequently happen that a second zygote could become well implanted before the uterus would be rendered utterly unreceptive.

The demonstration of tryptic enzymes in foetal ectoderm by Grafenberg[8]; the general appearance of the endometrium immediately surrounding the early human ova described by Miller[9], Linzenmeier[10], Peters[11], and others; the occurrence of canalized fibrin at the junction between the foetal and decidual tissue formed by a degeneration of those tissues as described by Langhans[12], Rohr[13], and others; the rapid proliferation of the chorionic epithelium and its subsequent invasion of

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[8] Grafenberg, E. Beiträge zur Physiologie der Ei-einbettung. *Ztschr. f. Geb. u. Gyn.*, 1910, Bd. 65, S. 1-35.

[9] Miller, J. W. Das jüngste operativ erhaltene menschliche Ei. *Berliner klin. Wochenschr.*, 1913, Bd. 50, S. 865-869.

[10] Linzenmeier, G. Ein junges menschliches Ei in situ. *Archiv. f. Gyn.*, 1914, Bd. 102, S. 1-17.

[11] Peters, H. Ueber die Einbettung des menschlichen Eies. *Leipzig und Wien*, F. Deuticke, 1899.

[12] Langhans, T. Untersuchungen über die menschliche Placenta. *Archiv. f. Anat. u. Entwickelungsgesch., Leipzig*, 1877, S. 188-267.

————. Ueber die Zellschicht des menschlichen Chorions. *Beiträge zur Anat. und Embryologie.* (Henle's Festgabe), *Bonn*, 1882.

[13] Rohr. Die Beziehungen der mutterlichen Gefasse zu den intervillosen Raumen der reifen Placenta, speciell zur Thrombose derselben ("weisser Infarct"). D. I., *Bern*, 1889.

the surrounding decidual tissues, as described by Hubrecht [14], Peters[11] and many others; and the sudden rise in the cyclogram at the time of nidation, as described by Samuels[15] — these indicate that substances of some sort are produced by the zygote, both during the early implantational and at later stages. The quantity, nature, and secretion of such substances might be determined by genetic factors.

It is certain, too, as shown by Leo Loeb[16], Corner[17], Courrier and Kehl[18], Knaus[19], Asdell[20], Pratt[21], and several others, that the effect of the implantation of the zygote is to cause the retention of the corpus luteum, which in turn secretes hormonal substances which cause the retention of the decidua. This decidua, according to Williams[22], increases markedly in thickness during the first few months of pregnancy, the cells of the surface epithelium covering the decidua change markedly in shape, as shown by Klein[23] and several others, and the uterus becomes unreceptive to other zygotes. The nature, degree, or rapidity of development of the retained corpus luteum might be dependent upon the substances produced by the zygote, which, in turn, likewise, might be determined by genetic factors.

The influence of environmental factors upon the operation of these genes is, similarly, quite unknown. Statistically, the appropriate type of

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[14] Hubrecht, A. A. W. Die Rolle des embryonalen Trophoblast bei der Placentation. *Zentralbl. f. Gyn.*, 1897, Bd. 40, S. 1206.

[15] Samuels, J. The cycle of the woman. *Jour. of Obs. and Gyn. of the Brit. Emp.*, 1938, Vol. 45, pp. 291-319.

[16] Loeb, Leo. The mechanism of the sexual cycle, with special reference to the corpus luteum. *Am. Jour. Anat.*, 1923, Vol. 32, pp. 305-343.

[17] Corner, G. W. Cyclic changes in the ovaries and uterus of swine, and their relations to the mechanism of implantation. *Carnegie Inst. of Wash. Publ., Contrib. to Embryol.*, 1921, Vol. 13, pp. 117-146.

[18] Courrier, R., and Kehl, R. Le deciduome experimental chez la lapine gestante. *Compt. rend. Soc. de Biol.*, 1930, T. 104, pp. 1180.

[19] Knaus, H. Zur Physiologie des Corpus luteum. *Archiv. f. Gyn.*, 1930, Bd. 141, S. 374.

[20] Asdell, S. A. The growth and function of the corpus luteum. *Physiol. Rev.*, 1928, Vol. 8, pp. 313.

[21] Pratt, J. P. Corpus luteum in its relation to menstruation and pregnancy. *Endocrinology*, 1927, Vol. 11, pp. 195-208.

[22] Williams, J. W. Obstetrics. *New York* and *London*, D. Appleton and Company, 1925.

[23] Klein, G. Entwickelung und Rückbildungen der Decidua. *Ztschr. f. Geb. u. Gyn.*, 1891, Bd. 22, S. 247-295.

twins is produced approximately two to three times as frequently by the gene for dizygotic twinning as by the gene for monozygotic twinning. The gene for dizygotic twinning seems, according to the work of Greulich[24], Komai and Fukuoka[25], and others, to be able to produce twins more readily in older women and in later pregnancies, whereas the gene for monozygotic twinning appears to be not especially influenced in its production of twins by such factors. This might be an explanation of the differences found by these authors in the occurrence, on the one hand, of dizygotic twinning, and, on the other hand, of monozygotic twinning.

SUMMARY

In order to determine the nature of the association between the factors for the production of monozygotic and those for the production of dizygotic twinning, 1,131 twins in 140 kindreds filed in the "A" File of the Eugenics Record Office, were analyzed in groups of two or three twins, and in units of from one to fifteen such groups. The percentage of like-sexed twins was determined for each of these groups and units, and the variations in the values of these percentages were analyzed by means of a graphical representation. The frequency distribution curves that were obtained in this way were definitely trimodal in nature. Three distinct modes appeared in one case; two distinct modes and a marked distortion of the left-hand portion of the median mode appeared in the other.

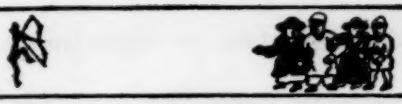
This distribution is interpreted to indicate that the large, median, modal class is composed of units produced by chromosomes that bear the genes both for monozygotic and for dizygotic twinning. On the other hand, the modes which center respectively at 100 per cent and at approximately 45 per cent are believed to be composed of units which contain chromosomes with the genes respectively for monozygotic or for dizygotic twinning with, in each case and reciprocally, the corresponding normal allelomorph of the other gene. The occurrence of three distinct types of chromosomes is thus demonstrated, and the two latter

[24] Greulich, W. W. Heredity in human twinning. *Am. J. Phys. Anthrop.*, 1934, Vol. 19, pp. 391-431.

[25] Komai, T., and Fukuoka, G. Frequency of multiple births among the Japanese peoples. *Am. J. Phys. Anthrop.*, 1936, Vol. 21, pp. 433-447.

types are believed to have developed from the first type by means of crossing over. The occurrence of such evidences of crossing over, therefore, indicates the occurrence of a genetic linkage between the genes for monozygotic twinning and those for dizygotic twinning. A study of the sexes of the ancestors of the twin-producing individuals indicates that such twinning is not a sex-linked character.

It is concluded, therefore, that monozygotic and dizygotic twinning in man is produced by two genetically linked genes which occur on an autosomal chromosome.



DEVELOPMENT OF THE HEAD IN THE SAME INDIVIDUALS[1]

BY MARCUS S. GOLDSTEIN

Division of Child Research, New York University Dental College

THE PROBLEM

CONSIDERABLE attention has already been given to antero-posterior and transverse growth of the head and the concomitant effect on form (Boas, '11; Meredith, '35; Goldstein, '36). All such studies, however, as far as the writer is aware, have been based on the cross-section method, that is, development being determined from measurements on different children at varying ages, or the data have been treated as if this were the case (Fleming and Martin, '33).

The writer has taken repeated measurements of the head at annual intervals on the same children, each child having had from two to six examinations. Despite limitations of treatment imposed by the character of the material, several pertinent questions relating to growth and form scarcely possible of consideration in a strictly cross-section study, could be and are examined in the following. A wealth of material recently made available by the Harvard Growth Study (Dearborn *et al.*, '38), including repeated observations of head width and length in the same subjects, has been utilized to check and clarify further the questions originally posited.

MATERIAL AND METHOD

The children, 115 girls and 141 boys between 2 and 16 years of age, were all of American birth and preponderantly of American parentage.[2] The economic circumstances of the group as a whole were probably

[1] I wish to acknowledge with thanks the helpful criticism of this paper by Dr. Harry L. Shapiro of the American Museum of Natural History.

[2] The ethnic origin of the parents and grandparents of substantially the same group as the present is tabulated in a previous study (Goldstein and Stanton, '35).

comfortable, the parents stemming mainly from the middle 'middle' class (teachers, physicians, dentists, etc.).

All measurements were taken by the writer. On account of indisposition or other reason the child was frequently not brought in for examination up to a month, occasionally up to two months, after the twelve month interval. This discrepancy of one and two months (47 cases or 7.4 per cent of the latter) was considered of no appreciable significance in the present instance, and no interpolation was therefore made in these cases. No data were used where the discrepancy was greater than two months.

The instrument used was the Hrdlička spreading calipers, repeatedly tested. Head length was measured between glabella and the farthest point on the occiput; width was the maximum transverse diameter.

Accuracy of observation is obviously of essential importance especially in a study of growth in the same individual, and every precaution possible was taken in this respect. It may be mentioned that at the time of measurement the diameter of the preceding year was not known. A measurement of head length was less than that of the preceding year, to the extent of one millimeter, never more, in 9 cases (4 ♂, 5 ♀); width of head, also not exceeding one millimeter, in 20 cases (9 ♂, 11 ♀) — a negligible number of the total 636. Of some interest is the apparently greater susceptibility to error in measuring width than length of head, a rather unexpected result. Several cases occurred in which increment was as much as 12 mm. in one year, strongly suggesting an error in measurement; these were omitted from the calculations.

DISTRIBUTION AND CENTRAL TENDENCY

Table 1 gives the central tendency and distribution of annual increment in length and breadth of the head, respectively. It was intended to present the length and width data in correlation form, but this purpose can be more adequately achieved with the extensive series of the Harvard data.

The amounts of increment in both length and width of head are evidently appreciable throughout the age period under consideration but appear especially high between 2 and 5 years, usually tapering off thereafter. There is also a definite tendency for mean annual increment in the length of the head to be greater than that in width; this is generally true of individual cases but the exceptions are frequent and sometimes considerable in extent. It might be recalled at this point that like incre-

TABLE 1

Means and numerical distribution of annual increment (mm.) in length and width of the head in the same individuals

AGE INTERVAL	HEAD LENGTH											HEAD WIDTH						
	Total No.	Mean (*mm.*)	Increment (*mm.*)									Total No.	Mean (*mm.*)	Increment (*mm.*)				
			0	1	2	3	4	5	6	7	9			0	1	2	3	4	5
Males			Frequency											Frequency					
2- 3	6	3.3	1	..	..	2	1	2	..	..	..	6	3.0	..	2	..	2	2	..
3- 4	33	2.9	2	3	13	4	5	4	..	1	1	33	1.7	3	10	15	4	1	..
4- 5	52	2.3	10	8	11	16	3	1	2	..	1	52	1.2	14	17	17	3	1	..
5- 6	56	1.3	18	13	17	5	3	..	..	..	..	56	1.1	13	24	17	1	1	..
6- 7	49	1.1	17	14	15	1	2	..	..	..	..	49	0.9	17	22	10	..	..	..
7- 8	33	1.5	6	10	11	6	..	..	..	..	..	33	0.8	10	19	4	..	..	..
8- 9	26	1.1	5	13	8	..	..	..	..	..	..	26	0.4	16	10	..	..	..	..
9-10	22	1.5	5	6	7	4	..	..	..	..	..	22	0.7	7	15	..	..	..	..
10-11	29	1.0	11	9	8	1	..	..	..	..	..	29	0.5	17	10	2	..	..	..
11-12	16	1.4	4	4	5	3	..	..	..	..	..	16	0.8	7	6	3	..	..	..
12-13	11	1.1	3	4	4	..	..	..	..	..	..	11	0.2	9	2	..	..	..	..
13-14	7	2.3	..	2	1	4	..	..	..	..	..	7	1.0	3	1	3	..	..	..
14-15	2	2.5	..	..	1	1	..	..	..	..	..	2	1.5	..	1	1	..	..	..
15-16	2	2.5	..	..	1	1	..	..	..	..	..	2	1.0	..	2	..	..	..	..

TABLE 1 (*continued*)

AGE INTERVAL	HEAD LENGTH											HEAD WIDTH						
	Total No.	Mean (*mm.*)	Increment (*mm*) 0	1	2	3	4	5	6	7	9	Total No.	Mean (*mm.*)	Increment (*mm.*) 0	1	2	3	4	5
Females																			
2- 3	4	3.0	..	..	2	1	..	1	..	..	..	4	2.2	..	..	2	1	1	..
3- 4	13	2.1	3	2	5	..	1	1	1	..	..	13	1.3	5	2	3	3	..	..
4- 5	23	2.5	3	4	5	3	6	2	..	..	..	23	1.5	4	8	9	2	..	..
5- 6	33	1.4	11	10	4	4	2	2	..	..	..	33	1.2	8	12	12	..	..	1
6- 7	40	1.2	10	15	13	2	..	..	..	..	..	40	0.8	14	21	5	..	..	..
7- 8	44	1.6	11	12	13	3	2	2	..	1	..	44	0.8	17	19	6	2	..	..
8- 9	37	1.0	14	13	6	4	..	..	..	..	..	37	0.6	20	12	4	1	..	..
9-10	32	1.3	9	11	8	2	2	..	..	..	..	32	0.5	21	7	4	..	..	..
10-11	19	1.2	4	8	6	1	..	..	..	..	..	19	0.6	11	4	4	..	..	..
11-12	17	1.4	2	7	7	1	..	..	..	..	..	17	0.7	9	5	2	1	..	..
12-13	16	1.3	1	9	6	..	..	..	..	..	..	16	0.7	8	5	3	..	..	..
13-14	10	0.8	4	4	2	..	..	..	..	..	..	10	0.8	4	4	2	..	..	..
14-15	3	0.7	2	..	1	..	..	..	..	..	..	3	0.3	2	1	..	..	..	..
15-16	1	0.0	1	..	..	..	..	..	..	..	..	1	0.0	1	..	..	..	..	..

Note: Age refers to mid-points, i.e. 3 years includes 2 yrs. 6 mos. to 3 yrs. 5 mos.

ments in width and length of head are not equivalent relatively, due to the smaller diameter of the former, and would actually indicate relative broadening of the head. Indeed, depending on the initial size, a slightly larger increment in length may still not give a lower cephalic index, e.g. one boy's head was 171 mm. in length and 136 mm. in breadth, cephalic index, 79.5; the annual increment was 5 mm. and 4 mm. for length and breadth, respectively, the cephalic index, however, remaining at 79.5. Further examples of this sort are indicated in a paper by Stewart ('36, p. 136).

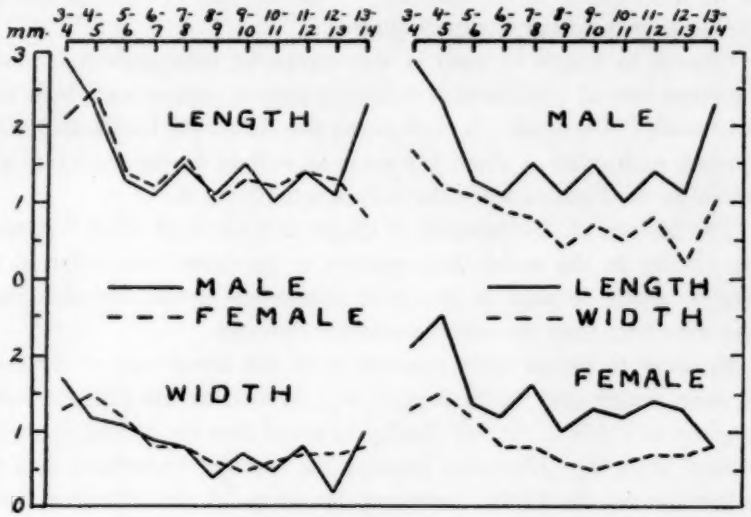


FIG. 1. CURVES OF MEAN ANNUAL INCREMENT IN LENGTH AND WIDTH OF HEAD IN THE SAME CHILDREN

The mean annual increments of Table 1 are graphically presented in Fig. 1. Considering first length, it is noted that there is an initial peak and subsequent decline until the seventh year, alike in both sexes except for a peculiar discrepancy in the very beginning in the females. After the 7th year, growth apparently levels off until 13 years, although pulsations of relative acceleration continue even during this interval; between 13-14 years there is marked acceleration in the males but actual deceleration in the females. The increased growth in the former is probably due to the greater development of the glabella region, beginning at this

Note: Age refers to mid-points, i.e. 3 years includes 2 yrs. 6 mos. to 3 yrs. 5 mos.

time probably as one of the manifestations of the pubertal complex in the males.

Pattern of growth in head length is very similar in both sexes, except for the intervals already noted, namely 3-4 and 13-14 years.

Turning to width of head, we find the same initial difference between the sexes, the peak of increment occurring at 3-4 years in the males, and at 4-5 years in the females. As in length, however, there is subsequent deceleration although the decline is much more gradual and less steep, continuing to about 9 years of age when a plateau begins, extending to 13 years, after which there is a suggestion of acceleration in the males but no deceleration in the females; — the number of cases at this last age, however, is altogether inadequate.

Growth in length of head is also compared with growth in width. The mean rate of increment is definitely greater antero-posteriorly than transversely. Curiously, in both sexes the curves of length and width approach each other at about 5-7 years as well as during the 13-14 year interval in the females when the curves actually meet.

The pattern of development of length and width of head is remarkably similar in the males, but appears to be rather dissimilar in the females, width of head in the latter apparently developing at a much more even pace than the antero-posterior diameter.

In order to secure some conception of the actual size of the head, the mean length and width respectively, as well as the cephalic index, are given in Table 2. It will readily be noted that the annual increment obtained from the differences between the average dimensions does not conform in pattern to that based on the means of the individual increments (Table 1). The discrepancy is undoubtedly due to the different methods of treatment of the data, namely, the longitudinal (even in a limited sense), in the first case, in contrast to the strictly cross-sectional procedure in the second instance. There can be little doubt that the developmental pattern indicated by the "longitudinal" results is much the more reliable, being based as it is on actual increments in the same individuals.

Attention may be called to an excellent discussion by Shuttleworth ('37) of the comparative reliability of results obtained by the cross-section and longitudinal methods of research in problems of growth.

The average head length and width each was also found for the Harvard data, considering children of north European ethnic stock only,

TABLE 2

Mean head dimensions and cephalic index between 3 and 14 years

AGE (*Years*)	MALE					FEMALE					MEAN CEPHALIC INDEX	
	No.	Length Mean	S.D.	Width Mean	S.D.	No.	Length Mean	S.D.	Width Mean	S.D.	Male	Female
3	35	175.3	5.1	139.2	4.2	15	169.4	5.1	137.2	5.5	79.4	81.0
4	60	176.7	7.7	141.2	5.4	31	172.5	6.1	138.0	5.9	79.8	80.0
5	73	178.1	6.8	141.7	4.9	41	174.7	6.4	140.0	5.7	79.5	80.1
6	66	179.1	7.4	143.4	5.1	45	175.6	5.8	141.7	5.3	80.2	80.7
7	58	178.8	6.6	144.5	4.6	61	175.8	6.0	142.5	5.1	81.1	81.1
8	51	180.0	5.8	147.5	4.9	53	176.8	5.2	142.7	4.5	82.1	80.7
9	37	183.1	5.3	148.5	5.3	46	177.9	5.8	143.5	4.8	81.3	80.7
10	34	186.0	5.4	149.0	4.8	41	179.3	6.1	144.1	4.5	80.3	80.4
11	33	187.3	6.1	149.4	5.2	30	180.0	6.1	145.8	3.9	79.8	81.0
12	18	189.1	..	149.3	..	22	181.5	..	146.3	..	78.9	80.6
13	13	186.4	..	149.0	..	17	182.6	..	147.3	..	79.1	80.7
14	14	186.5	..	151.2	..	10	184.4	..	147.4	..	81.1	79.9

TABLE 3

Mean dimensions of head and cephalic index of American children of North European Stock, at 6 and 17 years respectively (Harvard Growth Data)

AGE	No.	WIDTH Mean (*mm.*)	S.D. (*mm.*)	V. %	Range (*mm.*)	LENGTH Mean (*mm.*)	S.D. (*mm.*)	V. %	Range (*mm.*)	CEPHALIC INDEX Mean	S.D.	V.	Range
					Male								
6	129	141.4	5.1	3.6	129-158	176.6	6.0	3.4	165-193	80.2	3.4	4.2	71.4-87.6
17	171	149.8	5.2	3.5	137-166	191.7	6.8	3.5	175-212	78.1	3.2	4.1	70.3-85.0
					Female								
6	156	137.4	4.8	3.5	126-152	171.5	5.8	3.4	155-188	80.1	3.6	4.5	72.3-92.6
17	180	144.9	4.8	3.3	133-158	183.7	5.8	3.2	169-203	78.9	3.3	4.2	71.5-91.1

Note: Number of cases refers to both width and length. Cephalic indices are based on 114 cases, males; 140 cases, females, both at 6 and 17 years.

at 6 years and the same children at 17 years;[8] 114 males, 140 females. The difference between the averages was of course the same as the mean of the individual increments. Additional measurements, those available at 6 years but not at 17, and others at 17 years but not at 6 years, were combined with the previous data in order to discern the effects on the averages. The effects did not appear substantial and the greater number of cases was utilized for the mean dimensions given in Table 3.

The data indicate the usual relative lengthening of the head with age (diminished cephalic index) in both males and females, slightly less so in the latter. Absolute variability does not appear to change appreciably between 6 and 17 years, except perhaps in the length of head in males. Relative variability as measured by Pearson's coefficient of variability also is practically alike at 6 and 17 years in both length and breadth of head, males and females. Form of head, however, seems somewhat more variable than the absolute dimensions.

TABLE 4

Mean increment in head diameters of the same children between 6 and 17 years of age (Harvard Growth Data)

		HEAD WIDTH					HEAD LENGTH				
	No.	Mean	S.D.	C.V.	Range	PER CENT OF INITIAL SIZE	Mean	S.D.	C.V.	Range	PER CENT OF INITIAL SIZE
		(*mm.*)	(*mm.*)	%	(*mm.*)		(*mm.*)	(*mm.*)	%	(*mm.*)	
Male	114	8.1	2.3	28.4	3-16	5.7	15.2	3.4	22.4	7-30	8.6
Female	140	8.0	2.3	28.8	3-18	5.8	12.7	2.9	22.8	4-22	7.4

Table 4 indicates the mean increment between 6 and 17 years in the same individuals. This is manifestly substantial. Interestingly, increment in width of head is practically identical in both sexes, absolutely and relative to initial size, whereas increment in length of head is definitely less in the females than in the males, both absolutely and relatively. Variability is quite high, discernible in the range and in the coefficient of variability.

A number of individual growth curves were plotted, largely utilizing the Harvard data for this purpose. These data are readily available and

[8] Age had reference to mid-points, i.e. 6 years included 5 years, 6 months to 6 years, 5 months; similarly for 17 years.

the curves will therefore not be reproduced. The most striking result as it appeared to the writer was the wide array of developmental patterns discernible both in length and width of the head, evidently indicative of marked individual variability. It seemed, however, that whatever the developmental pattern, the total increment was often quite similar or the same. A more detailed analysis by age is in order but could not be attempted at the present time.

EFFECTS OF INITIAL SIZE OF HEAD

The question arose whether initial size of head had any effect on amount of increment or pattern of growth. In attempting to resolve this question, increments were segregated according to whether the head dimension (length and width, respectively) was below or above the average at each age. The results were: length of head, no apparent correlation, mean increments in each category differing only slightly and in no regular order. This was also true of width of head in the males. In the females, on the other hand, as indicated in Table 5, the smaller heads transversely (below average) manifested a consistently albeit slightly greater increment at every age interval.

TABLE 5

Mean increment in width of head of females according to whether initial dimension in the subjects was below or above the average

	AGE INTERVAL							
	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11
Below average	(6) 1.9	(14) 1.8	(20) 1.5	(23) 0.9	(29) 1.0	(24) 0.7	(18) 0.6	(11) 0.7
Above average	(7) 0.9	(10) 1.0	(14) 1.0	(18) 0.6	(15) 0.5	(13) 0.5	(14) 0.3	(11) 0.5

Note: Figures in parentheses refer to number of cases.

The Harvard material was first utilized in essentially the same manner, total increment between 6 and 17 years in each case being segregated also according to whether the length or width of head of the individual at 6 years was below or above the average of all the cases at 6 years. Interestingly enough, increment in length of head was found to be definitely related to initial size. The differences in increment between the "long" and "short" heads, and in favor of the latter, were:

males, 1.5 mm., females, 1.9 mm., each being statistically significant ($D/P.E._{diff.}$ 3.9 and 5.0, respectively). Width of head, however, was not much affected by initial size, the differences in increment between the "broad" and "narrow" heads, also in favor of the latter, being: males, 0.8 mm., females, 0.6 mm. ($D/P.E._{diff.}$ 2.6 and 2.2, respectively).

A more refined method of treatment with reference to influence of initial size was feasible with the Harvard data and the results are given

TABLE 6

Mean increment in head dimensions between 6 and 17 years according to initial size (Harvard data, American children of north European stock)

	WIDTH							LENGTH						
	125-129	130-134	135-139	140-144	145-149	150-154	155-159	160-164	165-169	170-174	175-179	180-184	185-189	190-194
							Male							
No.	1	8	23	52	23	6	1	...	11	34	36	21	8	4
Mean	8.0	8.8	8.8	8.0	7.7	7.2	10.0	...	15.9	15.9	15.1	14.0	13.9	16.5
							Female							
No.	7	22	62	40	7	2	...	13*	35	51	29	10	2	...
Mean	10.6	8.5	7.7	7.7	8.3	7.0	...	13.3	13.3	12.8	11.7	11.6	12.5	...

* One case with 155 mm. length included in 160-164 category.

in Table 6. Here also and perhaps in clearer fashion we find a definite tendency for the "short" heads to manifest greater increment than the "long" heads during a fairly considerable interval of time. Indeed, this would appear to be the case in width of head also, namely, the "narrow" heads indicating more or less greater increment in general than the "broad" heads. An apparent contradiction, maximum dimensions exhibiting large increments, is probably due to paucity of numbers in these categories, although it is also possible that the tendency is reversed in cases with exceptionally large dimensions.

It may be mentioned under this section that a high annual increment (in the New York University material) was generally followed by a lower amount, and a very low increment was most often succeeded by the same or a higher amount.

MENARCHEAL AGE AND GROWTH OF HEAD

The relationship of menarcheal age in girls to development of the head is manifestly a matter of considerable interest. The writer is greatly indebted to Dr. Frank K. Shuttleworth of the Institute of Human Relations of Yale University for generously making available to him the material given herewith on this point. The data are from the Harvard Growth Study. A full exposition of the nature of the

TABLE 7

Relationship of menarcheal age and development of the head in girls (Harvard Growth Data)

AVERAGE (*mm.*)	WIDTH			LENGTH		
Menarche (*Years and months*)	Early	Middle	Late	Early	Middle	Late
	Before 12-5	12-6 to 13-5	After 13-5	Before 12-5	12-6 to 13-5	After 13-5
Age (midpoints)	(72)	(108)	(68)	(72)	(108)	(68)
6.0	137.3	138.4	....	171.1	171.8	....
7.0	139.7	138.8	137.6	172.2	173.0	169.5
8.0	140.7	140.0	138.6	174.2	174.3	172.5
9.0	141.5	141.0	139.3	176.1	175.9	173.7
10.0	142.3	141.7	140.1	178.1	177.5	175.8
11.0	143.5	142.5	140.9	180.2	179.2	177.8
12.0	144.7	143.6	141.7	182.4	181.2	179.6
13.0	145.5	144.6	142.5	183.6	182.8	181.3
14.0	146.0	145.3	143.4	184.1	183.7	182.6
15.0	146.1	145.5	144.0	184.0	183.6	183.1
16.0	146.0	145.4	144.0	183.9	183.4	183.0
17.0	146.1	145.3	143.9	183.9	183.7	183.0
18.0	145.7	145.4	144.0	184.0	183.7	183.3
19.0	....	145.4	143.9	183.8	184.2	183.9

Note: Figures in brackets refer to number of cases.

material may be obtained in a recent monograph by Dr. Shuttleworth ('37) wherein menarcheal age is correlated with longitudinal development of other characters in the same girls dealt with herein.[4]

Table 7 presents the results. The girls, 248 in number, were divided according to what was considered early, middle, and late menarche, corresponding in age to (1) before 12 years, 5 months; (2) 12 years, 6 months to 13 years, 5 months; and (3) after 13 years, 5 months. It is to be remembered that measurements were made on the same girls at all ages, that is, a girl beginning menstruation at 12 years and 8 months

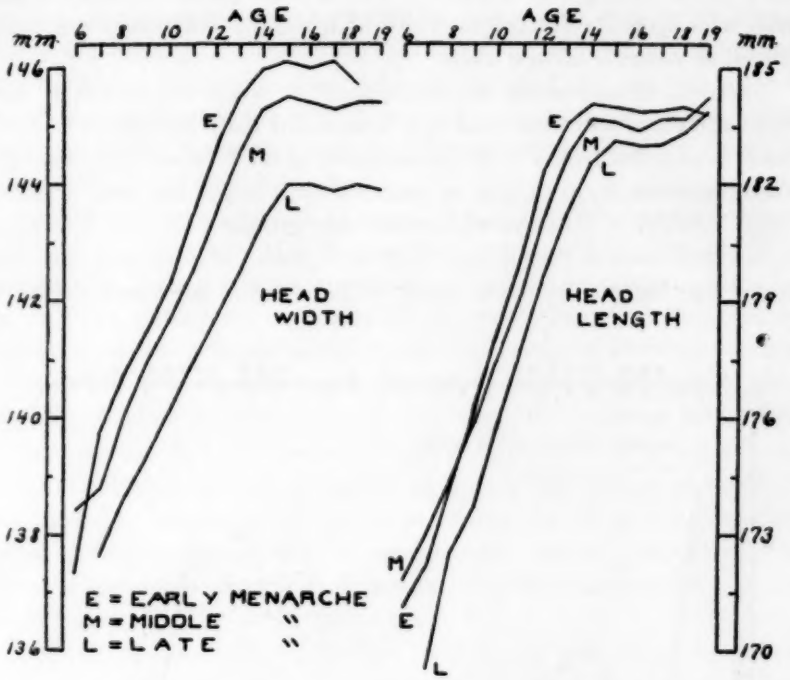


FIG. 2. GROWTH CURVES OF WIDTH AND LENGTH OF HEAD IN GIRLS ACCORDING TO AGE OF MENARCHE

[4] Dr. Shuttleworth writes with regard to the material, "In deriving these data we divided each of the three groups into those measured nearest odd numbered birthdays (7, 9, 11, etc.) and those measured nearest even numbered birthdays and then combined the two groups giving observation points at annual intervals although the original measurements during the later years of the Harvard Growth Study were taken only every other year."

is considered in the "middle" menarche category from 6 years to 19 years of age.

Turning to the tabular matter, or better still, to the graphic illustration of the data in Fig. 2, we note several remarkable results. First, that there is a definite and generally consistent relationship between age of menarche and mean size of head, especially in the transverse diameter. In other words, the dimensions are largest in girls of early menarcheal age, next in those of the middle period, and least in those with late menarche. The differences, although not marked are tangible, particularly in the early group in contrast with the late group. Moreover, and also with special reference to width of head, the differences are maintained at virtually all age levels.

Second, in contrasting the development of width and length of head with reference to menarcheal age, it is noted that the influence of the latter is perceptibly less in the development of the head antero-posteriorly than transversely; in fact, at 19 years the head length has become practically identical in all three menarcheal age groups while the divergence in width of head is even greater than at 6 years. Incidentally, it may be noted that the smaller initial length of head in the late menarche group

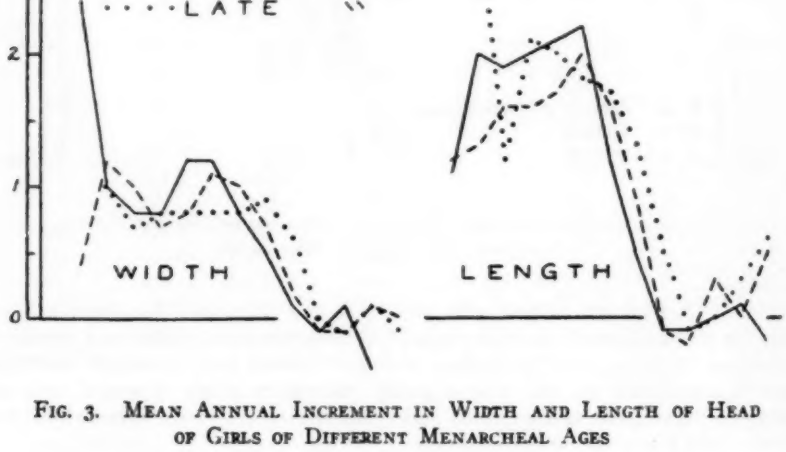


FIG. 3. MEAN ANNUAL INCREMENT IN WIDTH AND LENGTH OF HEAD OF GIRLS OF DIFFERENT MENARCHEAL AGES

has increased more than the longer initial length of the early menarche group.

Third, stability in size or virtual cessation of growth apparently occurs in both width and length at about 13 or 14 years of age in the early and middle menarche girls, although there is some slight increase in length later in the middle menarche group. In late menarche, on the other hand, and this in both width and length of head, a plateau in growth pattern commences a year after, namely, at 15 years; here too there seems to be a slight additional increment in length later, between 17 and 19 years.

Let us turn to pattern of growth from the point of view of annual increment (Fig. 3). Considering first the width of head and not counting the high increment between 6-7 years, we find that the maximum is reached at 11 years in the early group and 12 years in the middle group, whereas in late menarche there is a virtual plateau between 7 and 14 years with deceleration thereafter.

Regarding head length, it is perceived that growth is generally somewhat more rapid than in the transverse diameter, and also that it differs appreciably from the latter in pattern. Here the maximum is attained at 12 years in both the early and middle menarcheal ages, followed by deceleration, while in late menarche there are peaks of increment both at 8 years and at 10 years of age, although it is not until after 13 years that deceleration becomes marked. In brief, the evidence as a whole seems to point to a definite tendency for (1) maximum growth in the head (excluding the high increment in early childhood) to occur about or somewhat before the time of menarche, or the maximum is reached at an earlier age in early than in late menarche; and (2) maturity in the sense of cessation of growth is attained earlier (about a year) in the early than in the late menarche group.

It may be mentioned that others have shown with regard to stature and other characters (Boas, '32; Shuttleworth, '37), that early menarche is associated with early maturity and late menarche with late maturity, as is here suggested in the development of the head.

Finally, the total increment between 7 and 18 years in the several menarcheal age groups relative to initial size, is as follows: *width of head* — early menarche, 4.3 per cent; middle period, 4.8 per cent; late menarche, 4.7 per cent: *Length of head* — early menarche, 6.9 per cent; middle period, 6.2 per cent; late menarche, 8.1 per cent.

Total increment is evidently greater relatively as well as absolutely in head length, and the higher total in the late menarche groups is of particular interest.

HEAD FORM (CEPHALIC INDEX)

It has long been known that the form of the head is broader relative to length in the child than in the adult. This, however, was with reference to average conditions only. Questions such as whether the latter was true in all cases, or whether initial form of head had any effect on

TABLE 8

Mean increase and decrease in cephalic index points in same children segregated according to initial form of head

	DOLICHO-CEPHALIC (x-75.9)	MESO-CEPHALIC (76.0-81.4)	BRACHY-CEPHALIC (81.5-86.9)	HYPERBRACHY-CEPHALIC (87.0-x)	TOTAL
	N.Y.U. children, both sexes: any 4-year interval between 2-16 years.				
No change (0±0.4)	(6)	(21)	(12)	(2)	(41) 0.23
Mean increase	(6) 0.95	(10) 0.77	(2) 0.70	(1) 1.60	(19) 0.86
Mean decrease	(4) 0.82	(32) 1.04	(44) 1.38	(8) 1.68	(88) 1.26
Maximum increase	1.5	1.4	0.7	1.6	
Maximum decrease	1.6	1.9	3.3	2.6	
	Harvard growth data: between 6 and 17 years				
Male					
No change (0±0.4)	(2)	(10)	....	...	(12) 0.2
Mean increase	.... ..	(6) 1.2	.... ..	... ..	(6) 1.2
Mean decrease	(12) 2.0	(42) 2.5	(40) 2.9	(2) 3.2	(96) 2.6
Maximum increase	..	2.4	..	..	
Maximum decrease	2.9	4.9	6.6	3.8	
Female					
No change (0±0.4)	(1)	(19)	(4)	(1)	(25) 0.2
Mean increase	(8) 1.3	(13) 1.3	(2) 0.8	... ..	(23) 1.3
Mean decrease	(6) 2.0	(46) 1.8	(35) 2.4	(5) 2.5	(92) 2.1
Maximum increase	3.3	2.5	1.0	..	
Maximum decrease	3.4	6.1	5.0	3.2	

Note: Figures in brackets refer to number of cases.

subsequent changes, and the like, have hitherto, to the writer's knowledge, received no attention.

The Harvard Growth Study has been utilized in this instance as in the preceding, to check findings previously reached with the writer's material. In the original material (New York University children), changes in the cephalic index were noted over a period of 4 years, in the same individuals, of course. Both sexes were necessarily combined in order to attain a tolerable series. As for the Harvard data, however, changes in the index were noted between 6 and 17 years, in the same individuals of north European ancestory only, and with regard to sex.

The possibility of initial form of head exerting some influence on development or ultimate shape is manifestly a matter of interest, and has received attention in conjunction with the changes taking place in general. Definition of the several cephalic index categories (dolichocephaly, mesocephaly, and brachycephaly) followed Stewart's ('37, p. 137) recommendations to the Advisory Committee on Anthropometric Interests of the American Association of Physical Anthropologists.

It should also be mentioned that the New York University data were first divided according to age, but since no essential difference was observed in the results thus obtained and the summation of the ages, i.e. any 4-year interval occurring between 2-16 years, the summation only is tabulated.

The results are given in Table 8. Considering first the incidence of increase, decrease, or stability in index, we may turn to Fig. 4 for a graphic presentation on this point. With reference to initial head form, it is seen that dolichocephaly is actually characterized by a tendency to increase in cephalic index; this is especially marked in the combined sexes over a 4-year period, but is also definitely perceptible in the females between 6 and 17 years. What is more, this tendency is absent, and instead, a marked trend for a decrease in index, is apparent in mesocephaly, and even more so in brachycephaly. Again this phenomenon is more clear in the combined sexes and in the females of the Harvard group. A fair percentage of cases manifests no appreciable change in index whatever, although this manifestation likewise tends to become less common from dolicho- to brachycephaly. The differences between the sexes, already intimated, are quite interesting. An increase in index, even stability, is definitely more common in the females than in the males. This may possibly be explained by the fact that there is a comparative lack of development in the glabella region in the females, with

the chance for increment to be relatively greater in width than in length, or an increased cephalic index, consequently more likely of occurrence than in the males. In this connection it may also be recalled that the mean cephalic index in the females is usually, if not always, more or less higher than in the males.

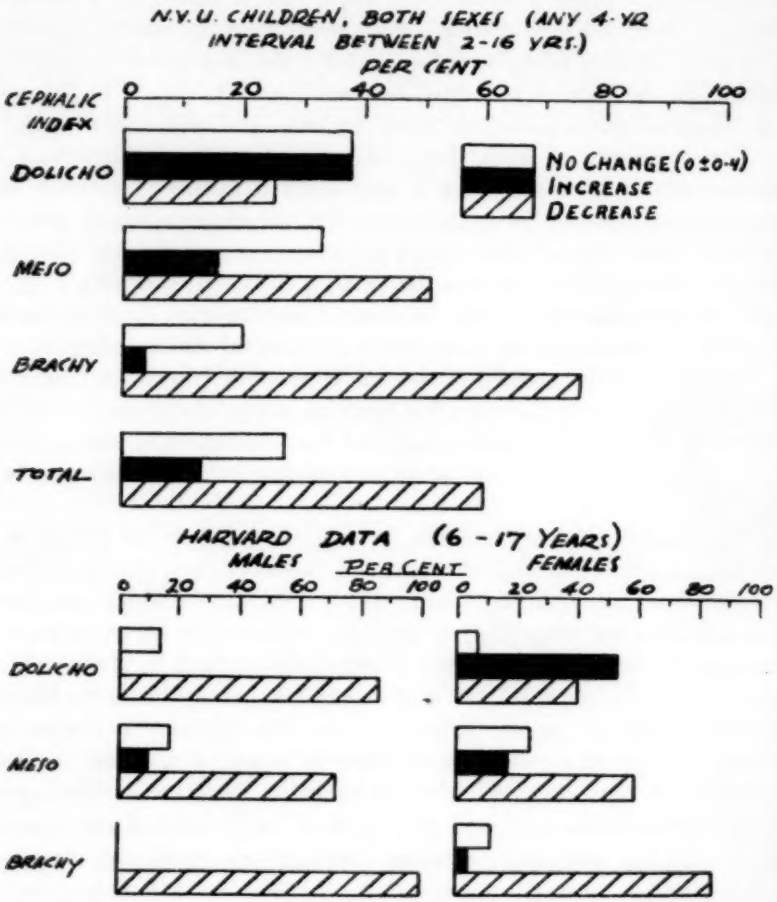


FIG. 4. PERCENTAGE OF CASES MANIFESTING NO CHANGE (0±0.4), AN INCREASE, AND A DECREASE, RESPECTIVELY, IN CEPHALIC INDEX DURING THE INDICATED INTERVALS OF TIME

It should also be noted that a combination of the sexes of the Harvard data would obviously give a remarkably close approximation to the figure depicting both sexes in the New York University children, and this despite the fact that the latter refers to a 4-year interval and the former to an 11-year period.

The total conditions irrespective of initial form merely reaffirm the preponderance of a diminution in cephalic index, as well as the not infrequent occurrence of virtual stability, even increase, of the index, each in the same individuals over a period of years.

Another query, corollary to the preceding discussion, is that concerning *extent* of increase or decrease in the cephalic index. This matter is also considered in Table 8. Noting first the conditions in general, indicated in the last column, we find that the *decrease* in index is in fact greatest in extent as well as most common in occurrence. With regard to initial form of head, there is the suggestion, to say the least, that the head tends to become relatively broader in dolichocephaly and relatively longer in brachycephaly, each in the same individuals over a period of time. Indeed, this phenomenon could also be interpreted from the relative frequencies of stability, increase, and decrease, respectively, occurring in the several head form categories, already described in Fig. 4.

In this connection it should perhaps be mentioned that the determination of how much of a change in index is significant, is outside the writer's province. The cephalic index is a proportion, of course, and its purpose, if understood correctly, is to give some indication of form. To what extent a difference of one or two points in the index figure, and at the various levels of the index, would actually affect form, is a matter of conjecture at present. Nevertheless, broad categories have been long recognized as defining relatively narrow, medium, and broad shapes of the head. To be sure, one category merges into the other, and a difference of an index point at the demarcation of two categories probably means little or nothing. On the other hand, it has been a common practice to segregate the indices of any group according to the three broad classes indicated above, namely, as dolicho-, meso-, and brachycephalic, and then to make comparisons of a like segregation in other groups, using this method as an aid in ethnic determination or analysis. With these circumstances in mind, it was considered rather pertinent that the factor of age be considered not only with regard to mere change in index, but also with respect to the transition from one cephalic category to another in the course of time, this, it is to be re-

membered, in the same individuals. This is the question considered in Table 9.

The results are exceedingly interesting. First, it is clearly indicated that a substantial proportion of cases do change from one index category to another, practically 17 per cent during any 4-year interval between 2 and 16 years in the combined sexes, and over 30 per cent of the children

TABLE 9

Changes from one cephalic index category to another in the same children over a period of four years and eleven years, respectively

	CEPHALIC INDEX					
	Dolicho to Meso	Meso to Brachy	Hyperbrachy to Brachy	Brachy to Meso	Meso to Dolicho	Brachy to Dolicho
	N.Y.U. children, both sexes: any 4-year interval between 2 and 16 years					
No.	5	1	4	12	3	....
Mean	0.8	0.2	2.3	1.3	1.7	....
Range	0.3-1.6		1.5-2.9	0.3-2.2	1.0-2.9	....
Change in means	75.4 to 76.2	81.3 to 81.5	88.0 to 85.7	82.0 to 80.7	77.4 to 75.6	....
	Percentage of total number (148) = 16.9					
	Harvard growth data: between 6 and 17 years					
Male						
No.	1	1	2	25	13	1
Mean	0.3	1.5	3.2	3.2	3.2	6.6
Range			2.6-3.8	1.2-5.6	0.7-4.9	....
Change in means	75.8 to 76.1	80.3 to 81.8	87.6 to 84.4	83.0 to 79.8	78.0 to 74.8	81.5 to 74.9
	Percentage of total number (114) = 37.7					
Female						
No.	4	2	2	23	12	....
Mean	1.9	2.2	2.2	2.5	2.7	....
Range	0.8-3.3	1.8-2.5	2.2-2.2	0.4-5.0	0.8-6.1	....
Change in means	75.1 to 76.9	80.3 to 82.5	87.8 to 85.6	82.7 to 80.2	77.5 to 74.8	....
	Percentage of total number (140) = 30.7					

between 6 and 17 years. Of interest also is the somewhat greater tendency to change of category in the males than in the females. Second, it is plain that the most common transition is from brachycephaly to mesocepahly. Rather surprising is the relatively high proportion of cases changing from meso- to dolichocephaly noted in the children of the Harvard study. Third, the extent of change in the transition from one category to another, in terms of index points, even on the average, is substantial, especially in the transition from relatively broad to relatively narrower classes. In one case, remarkable enough, the transition is from clear brachycephaly to definite dolichocephaly. The range in extent of change also demonstrates the appreciable fluctuations taking place, and again in largest measure in the transition from brachy- to mesocephaly or meso- to dolichocephaly. The changes in the actual indices, also tabulated, may still better define the extent and type of transitions from one cephalic index category to another.

Perhaps of collateral interest is the work of Mies and Duckworth, respectively, cited by Stewart ('36, p. 134). A positive correlation is indicated between size of head and thickness of tissues, both antero-posteriorly and transversely; i.e., the longer the head the greater the thickness of tissues in frontal and occipital regions; similarly, increasing width of head was associated with correspondingly greater thickness of tissue in the parietal regions. Moreover, it was found that the extent of difference in the length/breadth index of the head (cephalic index) from that of the skull (cranial index), was tangibly affected by *shape* of head, the differential being greater with increasing relative roundness. In explanation of this phenomenon, Stewart suggests (p. 137), "Assuming that the indicial difference increasing with roundness of head is statistically significant, this can be accounted for probably on the basis that with increasing brachycephaly the points of maximum breadth on the head and skull approach an alignment and have greater thickness of tissue intervening. Perhaps, on the other hand, in dolichocephaly the points of maximum breadth on the head and skull become more widely separated antero-posteriorly and thus allow some compensation for the tissues."

It should be pointed out in conclusion that the results of the present study refer largely to mesocephalic groups. Whether or not the same conditions would obtain in preponderantly dolicho- or brachycephalic stocks is a matter of future investigation.

SUMMARY

An enquiry was made into the changes in dimensions and form of the head (length, width, and cephalic index) with age in the same individuals. Some 256 children of American birth between 2 and 16 years of age were measured by the writer at annual intervals over a period of 2 to 6 years; data on the same boys and girls between 6 and 17 years of age, given in the Harvard Growth Study, were utilized as comparative and check material. The results were:

1. Length of head — annual increment high between 2 and 5 years, dropping sharply thereafter until 7; a plateau then with pulsations of growth till about 13 years when definite acceleration in males, but deceleration in females.

2. Width of head — comparatively high annual increment between 2 and 4 years, declining thereafter gradually and not as steeply as in length, especially so in females.

3. Mean annual increment in length of head is greater than that in width. In many individual cases of both sexes, however, an annual increment in width was the same or more than that in length. Growth pattern of length and width was very similar in males, dissimilar in females.

4. Variability of mean diameters of the head apparently did not change appreciably with age. Degree of variability was very high in individual increments between 6 and 17 years of age.

5. Increment was more a function of age than of initial size, but the latter also appeared to exert some influence, the short and narrow heads, respectively, manifesting somewhat greater increment than the long and broad heads.

6. A high increment one year was generally followed by a lower increment the next year.

7. A definite relationship appears to exist between menarcheal age and size and development of head. In both length and width of head, most markedly in the latter, the dimensions are larger in girls with early menarche than in girls with late menarche. This size differential relative to age of menarche is maintained with remarkable consistency between 6 and 19 years of age in width of head.

8. Maximum growth tends to occur about the time of menarche, hence, earlier in girls of early menarche in contrast with girls of late menarche. Also, maturity in the sense of virtual cessation of growth is

attained about a year sooner in early than in late menarche, growth of the head in length in the latter finally approximating, even slightly exceeding, the corresponding dimension of the early menarche group.

9. Regarding change of cephalic index in the same individual in the course of time, the most common phenomenon is a drop in the index, or the indication of relative lengthening of head; a sizable proportion of cases, however, manifest no appreciable change in index whatever, and a number even exhibit an increase of index or relative broadening of the head.

10. A definite relationship between changes in index and initial form of head seems to exist; namely, the head tending to become, in the same ethnic group, relatively broader in dolichocephalics and relatively longer in brachycephalics.

11. A substantial proportion of cases — over 30 per cent between 6 and 17 years — change from one index category to another during the course of growth and development. The most common transition is from brachycephaly to mesocephaly, although that from meso- to dolichocephaly is not an infrequent one. Not only in number of cases but also the amount of change is apparently substantial in these transitions from one index category to another.

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THE PHYSIQUE OF WOMEN STUDENTS AT NEWCOMB COLLEGE OF TULANE UNIVERSITY

V. INCREASE IN STATURE AT COLLEGE, BASED ON REPEATED MEASUREMENTS OF THE SAME INDIVIDUALS

BY HARLEY N. GOULD

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IT HAS been brought out in previous papers that a remarkable accumulation of repeated physical measurements of the same individuals has been available for study at the Newcomb College for Women in New Orleans. In 1930 the writer included in a paper on stature and weight in college women some findings on the change in stature during college attendance, based on 875 individuals who had remained in college four years and been measured eight times at six month intervals. Since that time the records have continued to accumulate until at the end of the session of 1936-7 there were available 1505 individual series of height measurements, 1124 of them consisting of eight measurements over four years and 381 involving six measurements over three years (the measurement of seniors was discontinued in 1930). With this increased wealth of material it was possible to make a more detailed analysis of stature change in young women at that period of life when growth has been almost completed and in some has practically ceased.

MATERIAL AND METHOD

The data for this study have been taken from the records of the physical education department of the college, where each student is measured twice a year, fall and spring. There is no doubt that as research material the records are in some ways unsatisfactory. Height (without shoes) was taken by an anthropometer attached to the weighing

scale, while the subject was standing on the platform of the scale. This method would not be conducive to the highest accuracy. The time of day for taking measurements was not always the same, and undoubtedly diurnal variations in stature entered into the results. Changes in styles of hair-dressing over the period covered (1909 to 1937) have had some effect on height measurements. The attitude of the writer at the beginning of the study was somewhat skeptical, but certain trends have emerged so clearly and consistently as to give assurance of the value of the data, provided sufficiently large groups are used to calculate constants.

In the individual series of measurements of a particular student, the fluctuations mask the general trend. There may be a gain of a half-inch during one six-month interval, a loss of a quarter during the next, a standstill during the third, a gain of an eighth during the fourth, and so on. But if the increments of one hundred such series are averaged for each interval, a trend of small but certain increase in stature emerges.

The method of analysis of the trend in stature has been to subdivide the material into groups on the basis of several different variables and to plot the stature trend for each group. With the smallness of the increments, the material could not be too finely subdivided, if the results were to be significant. Variables which could easily be used as bases for subdivision were age and height at entrance to college, and, since the records include twenty-six graduating classes, the material could be divided into groups according to the years when the students entered college. It was possible also to extract two groups with a probable contrast in ethnic origin. The questions to be answered are: What are the effects, if any, of age and height at entrance to college on subsequent growth in stature? Do students of recent years grow differently from those of twenty or more years ago? Is there any difference, in the final part of the growth curve, between young women of different racial stocks?

In assembling frequency tables of change in stature, the stature difference, or increment, between two successive measurements was used as the variate. Thus from eight successive measurements seven increments were obtained representing stature changes during seven intervals. Records were made in inches, to the nearest one-eighth inch, and frequency tables were based on this system; but at the suggestion of Dr. Hrdlička the final constants have been converted into the metric system and reported in millimeters.

It should be made clear that the 1505 individual series are those remaining after all imperfect series were eliminated. No student's record was used if even a single measurement had been omitted. The same individuals enter into the calculations for every interval, within a group, except that 381 of the 1505 enter into the first five intervals only, since they were not measured after the junior year. No student's record was used at all which showed any obvious evidence of inaccurate measurement or recording. It is not possible, of course, to determine from a record whether a large stature change over a six-month interval is a real change or an inaccuracy. Sudden spurts of growth do occur. In practice, no record showing more than seven-eighths of an inch change in any interval was admitted into the data, and a good many very fluctuating records were also discarded.

In the tabular presentation of the data, the "interval" represents the time between successive measurements. Intervals 1, 3, 5, and 7 are the winters of the freshman, sophomore, junior and senior years respectively, and 2, 4, and 6 are the intervening summers. Since the students usually were measured in October and April, the summer and winter intervals are approximately equal. The mean increment for each interval, with its probable error, is given in millimeters. The number of students is less in intervals 6 and 7 (except in Table 3) because of the discontinuance of senior measurements in the last few years.

The curves of average change in height (Figs. 1 to 4, and 6) are graphic presentations of the tabular data. Each curve starts at zero at the time of the first freshman measurement, and the stature increments are added progressively, the intervals between measurements being plotted along the base line, and stature increment along the vertical lines.

Growth and age

The subjects were assembled in groups according to the nearest whole year of age at the time of the first measurement: for instance, the age 17 group contains those who were, in October of the freshman year, over 16½ and up to and including 17½ years of age. Only ages 16 to 19 were included.

It is evident from Table 1 and Fig. 1 that the girls aged 16 make such a gain in height during the first year and a half in college as to carry their curve considerably above the others, while the girls of 17, 18, and 19 years follow more nearly the same curve. The sixteen-

TABLE 1

Increments of growth by age

AGE 16			AGE 17		
Interval	No.	Mean increment (*millimeters*)	Interval	No.	Mean increment (*millimeters*)
1	187	3.62 ± .31	1	640	2.52 ± .16
2	187	2.39 ± .29	2	640	1.24 ± .17
3	187	1.58 ± .25	3	640	1.31 ± .13
4	187	.58 ± .30	4	640	.49 ± .14
5	187	1.09 ± .29	5	640	.70 ± .13
6	126	.35 ± .32	6	453	.47 ± .18
7	126	.91 ± .32	7	453	1.07 ± .17
Total.....		10.52	Total.....		7.80

AGE 18			AGE 19		
Interval	No.	Mean increment (*millimeters*)	Interval	No.	Mean increment (*millimeters*)
1	533	2.94 ± .17	1	145	3.37 ± .36
2	533	1.03 ± .18	2	145	.74 ± .32
3	533	1.33 ± .16	3	145	1.36 ± .32
4	533	.31 ± .16	4	145	.24 ± .32
5	533	.98 ± .17	5	145	.72 ± .33
6	420	—.21 ± .17	6	125	—.36 ± .35
7	420	1.22 ± .18	7	125	.91 ± .29
Total.....		7.60	Total.....		6.98

year-olds are obviously a group apart, in their growth behavior. If now we plot the growth curves for the successive age-groups in a slightly different way (Fig. 2) so as to bring the same chronological ages together along vertical lines, it appears that the older freshmen show in general more increase in stature at a given age than the younger freshmen do at the same age. The character of the curves, too, is different, the older students showing a sharper rise and promising a quicker termination. The consistent and progressive change in the nature of the curves, from that of the sixteen-year-old freshmen to that of the nineteen-year-old freshmen, certainly indicates a difference in the way growth is completed, and suggests that the freshmen aged

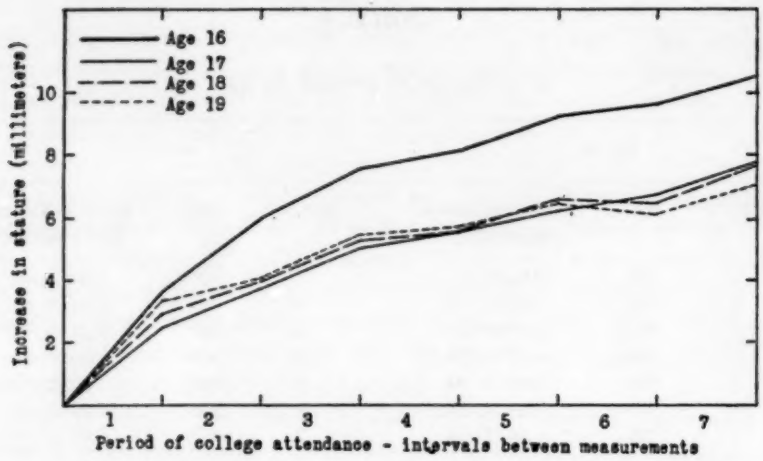

FIG. 1. INCREASE IN STATURE OF STUDENTS IN COLLEGE, ACCORDING TO AGE AT ENTRANCE

eighteen and nineteen are completing their growth in a spurt, perhaps because of a previous retardation.

These observations fit in very well with a fact repeatedly recorded regarding the stature of college women, by Jackson (1), Diehl (2), Barker and Stone (3), the present writer (4) and others. When

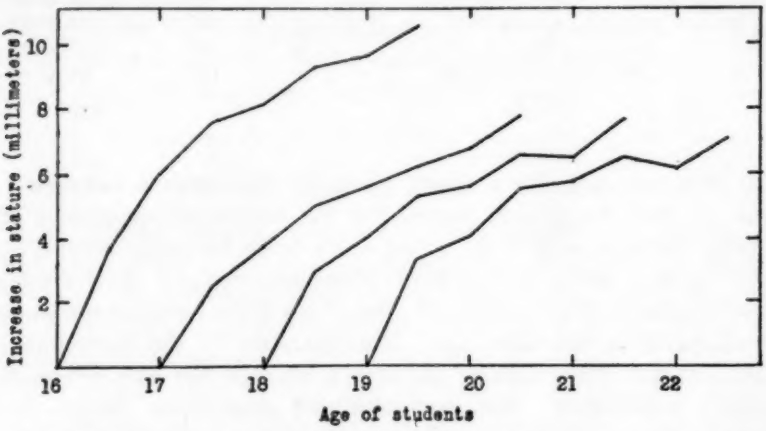

FIG. 2. INCREASE IN STATURE OF STUDENTS IN COLLEGE, ACCORDING TO AGE AT ENTRANCE, ARRANGED TO BRING CORRESPONDING AGES TOGETHER ALONG VERTICAL LINES

college women are grouped by age alone, on entrance to college, the older ones do not generally show any significant superiority in height. Diehl concluded from this that growth had been completed before entrance to college; but Young (5), Baldwin (6), Barker and Stone (3) and the present writer (4) have shown by repeated measurements on the same individuals that growth has not been completed, but that on the average young women continue to grow through the college years. In the light of the present data, it seems reasonable to conclude that girls who enter college at an early age are those whose physical growth has been accelerated and those who are older when they enter are those who have experienced some retardation but who make up for it, at least in part, by a late spurt of growth.

Growth and initial height

The same subjects used in the preceding section were regrouped on the basis of their stature at the time of the first measurement, regardless of age. Three groups were made: short, under 62 inches (157.5 cm.); medium, 62 and under 65 inches (165 cm.); and tall, 65 inches and over.

It appears that initial height is not a very important factor in determining the amount of growth during the college years, although it is so earlier (Boas, 9). The three curves representing the short,

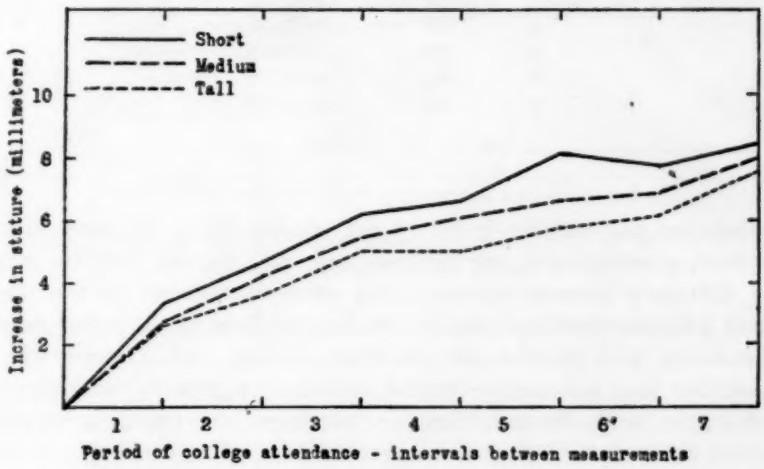

FIG. 3. INCREASE IN STATURE OF SHORT, MEDIUM AND TALL STUDENTS DURING COLLEGE ATTENDANCE

TABLE 2

Increments of growth by initial height

SHORT (under 157.5 cm.)			MEDIUM (157.5 cm. and under 165 cm.)		
Interval	No.	Mean increment (*millimeters*)	Interval	No.	Mean increment (*millimeters*)
1	369	3.37 ± .23	1	758	2.80 ± .15
2	369	1.31 ± .20	2	758	1.39 ± .15
3	369	1.52 ± .19	3	758	1.25 ± .09
4	369	.40 ± .18	4	758	.63 ± .13
5	369	1.52 ± .19	5	758	.59 ± .13
6	280	—.42 ± .22	6	570	.23 ± .16
7	280	.73 ± .22	7	570	1.11 ± .15
Total.....		8.43	Total.....		8.00

TALL (165 cm. and over)		
Interval	No.	Mean increment (*millimeters*)
1	378	2.66 ± .21
2	378	.97 ± .20
3	378	1.40 ± .20
4	378	—.02 ± .21
5	378	.72 ± .20
6	274	.41 ± .19
7	274	1.40 ± .18
Total.....		7.54

medium and tall students in Fig. 3 run consistently in the same order, the short growing most, the medium next and the tall students least. The difference between corresponding mean increments on the three curves is hardly significant statistically, but the form of the entire curves is consistent with the idea that the short students include many whose growth has been previously retarded and who are growing more rapidly at this time, while the taller ones include those who have more nearly reached their adult height before matriculation. The mean ages of the three groups have not been calculated but data formerly reported on some of the same material indicates that the taller students are no

older than the shorter and that such differences as there are in the three curves are not due to age.

Growth and date of attendance

It has been stated that the records used begin in the year 1909. In Table 3 and Fig. 4 the material has again been reassembled, in this case according to the periods when the students were coming to college, regardless of age or height. The groups represent, respectively, those matriculating during the periods 1909-14, 1915-19, 1920-24, 1925-29, and 1930-34, — all five-year groups except the first, which includes six college classes. The difference in the rate of growth among these groups is greater than among the groups arranged by age or height, and is interesting from more than one aspect.

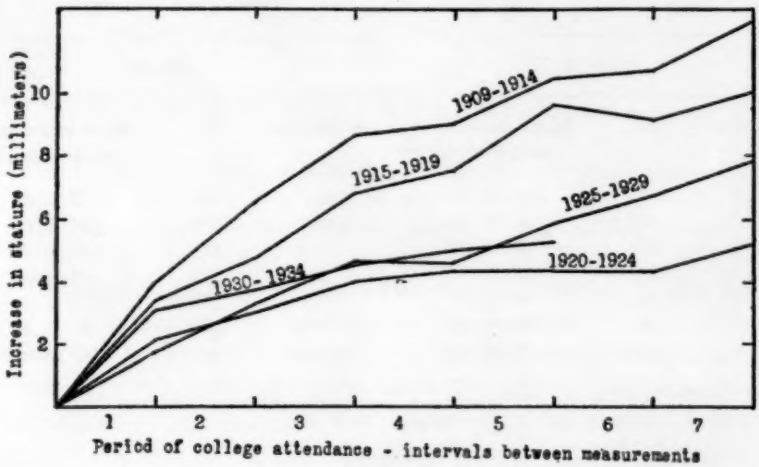

FIG. 4. INCREASE IN STATURE OF STUDENTS IN COLLEGE, BY GROUPS OF YEARS WHEN MATRICULATION TOOK PLACE

In the first place, the students entering during the first eleven years of the records (1909-1919) were obviously growing much more after entering college than the students of more recent years. It is known that the mean stature of all entering students at that early time was considerably less than it has been more recently. Fig. 5, taken from a contribution of Miss Elizabeth Spencer to the "Undergraduate studies of Newcomb College", shows the trend in height of entering freshmen

TABLE 3

Increments of growth by date of attendance

1909-14			1915-19		
Interval	No.	Mean increment (*millimeters*)	Interval	No.	Mean increment (*millimeters*)
1	201	4.00 ± .30	1	252	3.39 ± .24
2	201	2.54 ± .33	2	252	1.36 ± .27
3	201	2.09 ± .22	3	252	2.05 ± .23
4	201	.36 ± .27	4	252	.77 ± .24
5	201	1.50 ± .25	5	252	2.04 ± .23
6	201	.24 ± .24	6	252	—.48 ± .24
7	201	1.59 ± .24	7	252	.93 ± .23
Total.....		12.32	Total.....		10.06

1920-24			1925-29		
Interval	No.	Mean increment (*millimeters*)	Interval	No.	Mean increment (*millimeters*)
1	361	2.09 ± .24	1	310	1.73 ± .22
2	361	.92 ± .21	2	310	1.51 ± .22
3	361	.98 ± .19	3	310	1.46 ± .20
4	361	.36 ± .19	4	310	—.07 ± .20
5	361	.01 ± .21	5	310	1.25 ± .21
6	361	—.04 ± .20	6	310	.81 ± .21
7	361	.87 ± .19	7	310	1.18 ± .22
Total.....		5.19	Total.....		7.87

1930-34

Interval	No.	Mean increment (*millimeters*)
1	381	3.09 ± .19
2	381	.64 ± .19
3	381	.77 ± .18
4	381	.50 ± .20
5	381	.25 ± .19
Total.....		5.25 *

* To end of junior year.

from 1909 to 1936. As the students became taller on entrance, they grew less while in college. If it is true that the recent increase in stature of college students, not only at Newcomb but in colleges and universities generally, is associated with better child development and accelerated growth in early life, it is natural that the subsequent growth during the college years should be less.

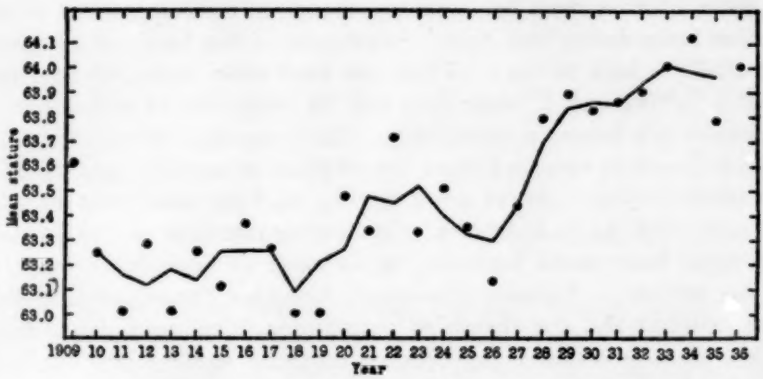

FIG. 5. TREND OF AVERAGE STATURE OF FRESHMEN, NEWCOMB COLLEGE, 1909 TO 1936
(Dots, actual mean statures; solid line, weighted 3-year moving average).

In the second place, it will have been noted in Figs. 1, 2, and 3 that there is a tendency to an irregular or zigzag course to the curves of growth, due to the winter increases in stature being greater than the summer increases, which in some cases are actually negative, though hardly significantly so. This was discussed in the writer's paper of 1930 (4), (cf. also Palmer, 7). In Fig. 4 it is seen that this irregularity comes chiefly in the history of students matriculating during the years 1909 to 1919. In recent years it is much less evident and, whatever the cause, there is less seasonal fluctuation in height increment.

The period 1920-24 gives a picture out of line with the rest. It was at first very puzzling that an entire group of 361 students should show practically no increment at all for a year and a half. A check on the events of the time from old year-books of the university, with photographs of the students, revealed that 1922-23 was the period when most of the girl students began to bob their hair. It is believed that the change in the style of coiffure affected the measurements so as to offset

the small increments of stature, and the 1920-24 curve does not therefore tell the truth about actual stature.

The curve for the period 1930-34 extends over only five intervals because, as has been said, the measurement of seniors was not continued beyond the class which entered in 1929.

In considering the change in growth curves of the students over the time of twenty-six successive academic classes, it would be interesting to know whether there has been any change in the composition of the student body during that time. Summaries of the locale of residence are available back to 1911. There has been some expansion of Newcomb's "service region" since then, and the proportion of students from a distance has increased accordingly. The percentage of students from outside Louisiana runs as follows (unweighted averages): 1911-14, 18.8 per cent; 1915-19, 19.0 per cent; 1920-24, 24.7 per cent; 1925-29, 29.1 per cent; 1930-34, 32.0 per cent. Considering that most of this increase has come from states bordering on or close to Louisiana (based on catalog records — Alabama, Mississippi, Arkansas, Texas, and Georgia), it is doubtful that the change in composition is of much importance, unless there is involved an influx of northern families into the Gulf Coast states for permanent residence, a point not easily checked.

It has been suggested that records of stature in women over a long period of time might be affected by current fads of posture going along with styles of dress. It can hardly be doubted that standing postures may be influenced by an attempt to conform to the "fashionable figure". It should be pointed out, however, that throughout the physical measurements of the Newcomb students, two measurements of stature were taken for each student at each examination: one, the "habitual" height, and a second, the fully erect height. Only the latter has been used in this study.

The amount of physical exercise taken by girls and young women in Louisiana has increased greatly in the last twenty years. Its effect on stature may have entered to a certain extent into our records.

Growth and racial stock

An attempt was made to classify the students on some ethnic basis. The only information at hand was, first, students' written statements of the national derivation of their parents and second, the statement of their religious preference. From these sources it was possible to assemble a group of 390 persons of allegedly North European, non-Jewish

TABLE 4

Increments of growth in Jewish and non-Jewish

NORTH EUROPEAN NON-JEWISH			JEWISH		
Interval	No.	Mean increment (*millimeters*)	Interval	No.	Mean increment (*millimeters*)
1	390	2.18 ± .20	1	200	3.13 ± .27
2	390	1.45 ± .20	2	200	.67 ± .29
3	390	1.33 ± .19	3	200	1.46 ± .26
4	390	.51 ± .18	4	200	.71 ± .29
5	390	.78 ± .19	5	200	1.03 ± .27
6	330	.08 ± .21	6	139	.37 ± .31
7	330	.81 ± .21	7	139	1.35 ± .28
Total.....		7.14	Total.....		8.72

ancestry (Scotch, Irish, English, Welsh, Danish, Swedish, Norwegian, Dutch, and mixtures of these, mostly from the British Isles) and a group of 200 students of the Jewish faith and so, presumably, of predominantly Jewish racial stock (regardless of country of origin though largely German). Imperfect as this classification is, it might be supposed to indicate some racial difference. The stature increments of these two groups are given in Table 4 and plotted in Fig. 6. The curves of growth are not different enough to be of any real significance.

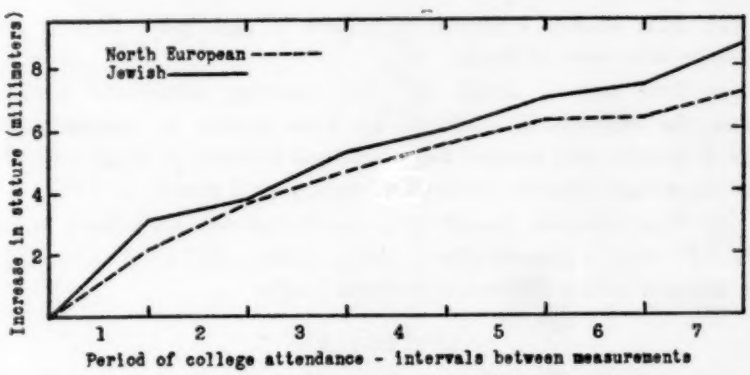

FIG. 6. INCREASE IN STATURE OF STUDENTS IN COLLEGE, BY ETHNIC DERIVATION

The Jewish students grow a little more in college, but they are of shorter stature (Gould, 8), which may partly or wholly account for the difference.

CONCLUSION

The whole picture presented by these data seems to be consistent, and to indicate that one of the influences on growth in the late 'teens is the amount of growth previously accomplished. It confirms the belief that very young college freshmen represent a physically accelerated group. It shows why it is unsafe to take progressive chronological ages for points on a growth curve when the ages are represented by different sets of individuals. Emphasis should be placed on the fact that the graphs represent only averages — only the composite of the individual changes between successive measurements — that each person has spurts and cessations of growth in stature, and perhaps not a single subject measured actually follows any of these curves.

SUMMARY

An analysis of the changes in stature of female college students, based on measurements of the same individuals over a period of years indicates:

(a) That college students of different ages, but in the same academic classification, are completing their growth in stature along different curves, and that the age at which the student enters is associated with previous physical development.

(b) That shorter students, regardless of age, grow slightly more in college than taller students.

(c) That over a period of years covering twenty-six academic classes, the students of earlier years were shorter on entrance, grew more in height, and showed more seasonal fluctuation in growth after entering college than the students of more recent years.

(d) That between Jewish and non-Jewish students there is very little difference in growth after entering college, and what there is may be associated with a difference in initial height.

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ON HUMAN SOCIAL BIOLOGY
III. ELEMENTS AFFECTING THE FORMATION OF THE MARITAL GROUP[1]

BY ANTONIO CIOCCO

INTRODUCTION

IN AN earlier paper (1938a) the writer discussed the method of approach to the study of human social biology, and reached the conclusion that more adequate observations on human social behavior are needed before one can reasonably expect to arrive at an understanding of the stable elements in the relations between men. In particular, a quantitative appraisal of the social behavior of contemporary man is desired because (a) greater and more accurate information can presumably be obtained about him and (b) observations on primitive and historical peoples and observations and experiments on other animals can then be most effectively utilized.

In accordance with this point of view an investigation based on unique material concerning problems of marriage has been undertaken. The immediate purpose is to contribute factual information about a vital aspect of human social activity. In addition, it is hoped to elucidate further certain general concepts advanced by the writer, since the marital group, although possessing distinctive features, is nevertheless only one of the many types of social groups into which human beings segregate. The characteristics of the marital group, its similarity and differences when compared to the mating of other animals and the question of the origin of the institution of marriage have already been discussed in the second paper in this series (1938b) which dealt with the elements involved in the breakdown of the marital union.

The present report brings forward data on another aspect of the marriage problem, that of marital selection. In other species of animals the phenomenon of mating is primarily and overtly a function of the

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physiological responses of the creatures concerned. In man, no matter how primitive, this activity is far more complicated since it involves physiological, psychical, social and, particularly, ethical factors. The most distinctive feature of human mating is that it is generally the consequence of the emotional state called love, or supposedly so. The measure of this condition, the variability in its manifestations, or the etiological factors responsible for it are unknown. Nevertheless, it is accepted that love, or deep mutual affection, is a prerequisite to marriage. Although it may be the dominant factor in human mating selection, other conditions must be satisfied before marriage takes place and these will be outlined in this study based on the information obtained about the circumstances which interfere with the marriage intentions of a group of young men and women.

MATERIAL

The source of the material has been described in the preceding paper (1938b) to which the reader is referred. For the purposes of this study, the writer has selected from the letters in his collection all those written by persons whose desire to marry encounters some difficulty, and who therefore seek advice about the problem. These letters total 450. Of them 333 were written by women and 117 by men.

From the nature of the sample it follows that all of these persons are literate, have a problem and are unable to solve it. In common they possess the characteristic of being unmarried and, as all of them definitely state, their deep affection is reciprocated by the desired spouse. The limitations imposed by the source of the material are well recognized and have been taken into account. These limitations, in the writer's opinion, are more than offset by the fact that these letters express ideas and feelings *given under no outside compulsion, suggestion, or stimulation.* Therefore, it would seem that they reveal to an unusual degree the concrete elements in social behavior — the individuals whose actions and rationalizations demonstrate their variable reactions to the social environment.

PRESENT AGE, AGE OF ONSET AND DURATION OF EMOTIONAL RELATIONSHIP

Among the individuals represented in this sample, 133 women and 86 men stated their age in years. The mean age of the women equals 22.5 ± .3, the median is 20.9 ± .4 years and the standard deviation

equals 5.2 ± .2 years. The men are older, having a mean age of 25.1 ± .4 years and a median age of 23.5 ± .5 years. They are also somewhat more variable in age, the standard deviation being 6.0 ± .3 years. From what knowledge there exists about the age of marriage, it seems safe to assume that, from this standpoint, these individuals are representative of the marriageable population. The median being lower than the mean age indicates that there is a concentration of individuals around the younger ages and a skewness of the distribution towards the older ages. The oldest recorded age is 48 years for the men and 45 years for the women.

Of greater interest, especially because no data on the subject exist, is the age of onset and the duration of the present relationship. The mean age of onset for the 25 men who reported this item is 20.3 ± .4 years and for 75 women it is 18.8 ± .3 years. The standard deviations are respectively 3.1 ± .3 and 3.3 ± .2 years. The age of 15 is the earliest recorded for the men and 13 years for the women. These findings, better than those on the age of marriage, illustrate the early age at which sexual selection takes place — even under the conditions of the present civilization. It will be noted that the females are more precocious than the males. This is clearly in accord with the differences in sexual maturity, but not so much as the differences between the marriage ages would seem to indicate.

The duration of the relationship between the members of each couple is on the average 3.6 ± .3 years for the men and 3.0 ± .2 years for the women. These figures are of course a function of the present age and are given here to demonstrate the seriousness with which the relationship has been considered as well as the length of time it has been maintained.

BASIC DISTURBING CONDITIONS IN THE PRE-MARITAL RELATIONSHIP

As has been stated, both the men and women of this sample of premarital groups seem to be definitely assured of a reciprocated deep feeling of affection. However, certain situations are manifest which, in the opinion of these persons, may interfere either with the chances of marriage or with the happiness of married life.

These situations may be said to arise from the interaction of two sets of factors: (1) the qualities or characteristics of the two partners, and (2) the evaluation of the consequences of these characteristics with respect to the proposed marital union. The first are here regarded as the basic disturbing conditions and the second as the immediate disturb-

ing conditions in the pre-marital relationship. To illustrate how the two component factors interact and are segregated let us consider, as an example, that a woman may complain of the promiscuous sexual behavior of the man because (a) it is immoral and she will not marry an immoral person, (b) he may find another woman and change his mind about marrying her, and (c) he will be unfaithful after marriage. The basic condition is here always the same: the sexual conduct of the man, but the immediate conditions are (a) her moral principles, (b) her doubts regarding the persistence of his affection and (c) her views about the sanctity of marriage. It is obvious, on the other hand, that the moral principles of the woman, for example, may be offended by other characteristics of the man — gambling, drinking, religious views — and thus the same immediate condition may arise from a variety of individual characteristics or, as it is termed here, basic conditions.

From the declarations of the subject it is possible to construct 10 categories of basic conditions. These are:

1. *Social status.* There is a difference in the familial, and cultural background of the man and woman. He or she was "born on the wrong side of the tracks", has had relatively limited educational advantages, etc. although the other individual qualities are above criticism.

2. *Religion and nationality.* As the heading indicates, this class contains those cases in which the basic condition disturbing the pre-marital group is the diversity in religion or nationality.

3. *Age.* There is a remarkable age difference between the man and woman. From the statements given it is to be noted that when the man is older than the woman, the criterion of "too old" varies considerably. On the other hand, apparently it is sufficient for the woman to be only one year older in order to create a doubt in the mind of either the man or woman regarding the suitability of such a marriage.

4. *Kinship.* This category is very homogeneous since it concerns those cases in which the pre-marital partners are first cousins.

5. *Marital status.* The other person is already married and is not legally separated from the spouse.

6. *Sexual conduct.* The condition included here arises from the present or past promiscuous sexual behavior of the other person.

7. *Temperamental traits.* Moodiness and jealousy are among the traits of the other person noted most often.

8. *Social vices.* Gambling and excessive drinking form the complaints grouped in this class.

9. *Somatic peculiarities.* The other person is relatively tall, short, etc.

10. *Inadequate income of the male.* The income of the man is regarded as insufficient.

The frequency with which the men and women of this sample report the existence of these categories of conditions is shown in Table 1.

TABLE 1

Basic disturbing conditions in the pre-marital relationship of 333 women and 117 men

BASIC CONDITIONS	WOMEN		MEN	
	Number	*Percent*	*Number*	*Percent*
Social status	70	21.0	33	28.2
Sexual conduct	51	15.3	22	18.8
Inadequate income (male)	46	13.8	14	12.0
Religion and nationality	42	12.6	15	12.8
Age	35	10.5	11	9.4
Marital status	34	10.2	5	4.3
Temperamental traits	25	7.5	9	7.7
Social vices	17	5.1	..	...
Kinship	8	2.4	3	2.6
Somatic peculiarities	5	1.5	5	4.3
Total	333	99.9	117	100.1

From the data in Table 1 it seems important to note:

1. The four categories of conditions represented most frequently are social status, sexual behavior, inadequate income of the male, and religion and nationality. These four classes of conditions are mentioned by over 60 percent of the women and over 70 percent of the men. Of minimum numerical importance are kinship and somatic peculiarities, which are regarded as basic disturbing elements by about 4 percent of the women and 7 percent of the men.

2. Those conditions deriving from qualities essentially social in a general sense — family, education, income, religion, nationality, occur

about 2½ times as frequently as those constituted by strictly individual characteristics, i.e. age, temperament, somatic peculiarities.

3. For both the men and women the order of frequency of the categories is about the same. The one main exception is that no man complains about gambling and excessive drinking by the woman.

The close similarity in the order of frequency of these conditions for both the men and women, even when it concerns the inadequate income of the male, deserves particular mention. On its face, this fact would indicate that the above conditions and their order of frequency reflect ideas, viewpoints and situations that transcend the differences in social conditioning and behavioristic characteristics attributed to the two sexes.

It should be especially emphasized that these conditions existed and most of them were perceived before the emotional involvement took place. This means that a deep affection can and does arise notwithstanding the kinds of personal differences shown here. Moreover, from the above data it would seem that the disturbing conditions are primarily due to factors which are extraneous to what biologically is regarded as sexual selection. The material consequently appears plainly to indicate that the problems for the pre-marital groups arise mainly from the superimposition of social considerations upon the elementary physical attraction. The manner in which this phenomenon occurs will be discussed in the remainder of the analysis.

IMMEDIATE DISTURBING CONDITIONS IN THE PRE-MARITAL RELATIONSHIP

The conditions described above represent a relative judgment of certain characteristics of the pre-marital partner. As has been pointed out, they have not actually disturbed the relationship between the man and woman but are, however, regarded as the basic elements that may eventually interfere with the possibility and happiness of marriage. The subjective evaluation of the effects such characteristics may have on the proposed marriage are considered here as the immediate disturbing causes. They are the rationalizations introduced to explain why such qualities are believed likely to affect the proposed marriage. From the statements made by the subjects it appears that these immediate conditions fall into four classes. They are:

1. *Affection.* The subjects believe that a particular quality of the partner may eventually bring about a decrease in the affection of either

of the two persons before the marriage and *therefore the marriage will not take place.*

2. *Principles.* The basic conditions noted are such that marriage would conflict with the moral and religious principles of either of the two partners or else bring upon them the effects of social sanctions.

3. *Marriage needs.* The subjects believe that the qualities of the other person will not satisfy the practical needs of married life, physical companionship, economic means, care of the offspring.

4. *Parental attitude.* There is active parental opposition to the marriage and the subject or the partner faces the dilemma of losing the practical aid of the parents or else disposing of the idea of marriage. In none of these cases is there present the question of "duty" or "obedience" to the parents.

The frequency with which the men and women of this sample refer to these immediate conditions is shown in Table 2.

TABLE 2

Immediate disturbing conditions in the pre-marital relationship of 333 women and 117 men

IMMEDIATE CONDITIONS	WOMEN		MEN	
	Number	*Percent*	*Number*	*Percent*
Parental attitude	111	33.3	29	24.8
Affection	109	32.7	39	33.4
Principles	74	22.2	33	28.2
Marriage needs	39	11.7	16	13.7
Total	333	99.9	117	100.1

From Table 2 it is seen that the most frequent immediate disturbing condition for the women is parental attitude, for the men it is affection. For both men and women the class of marriage needs is noted least often. The main difference between the two sexes is that the women regard parental attitude more often and principles less often as immediate disturbing factors than do the men.

One of the most interesting aspects of this classification and distribution is the little importance overtly given to the future needs of

matrimony. The great majority (almost 90 percent) of these men and women evince only interest towards the immediate business of getting married and seemingly do not believe that the basic condition which disturbs their pre-marital relationship will affect their married life.

Worthy of special comment are also the findings that show how infrequently these people have recourse to religious and moral concepts or to social sanctions. The idea that a basic condition is immoral, against the teachings of religion or will offend public opinion is openly expressed by less than 25 percent of the men and women of this sample.

On the whole, then, the impression obtained from the above data is that the immediate disturbing conditions in the pre-marital relationship are mainly of a practical nature and the attitude manifest by the subjects is a pragmatic one expressing little concern for the remote future or with metaphysical entities. However, the significance of these observations can be perceived more clearly by studying the association between basic and immediate conditions.

ASSOCIATION OF BASIC TO IMMEDIATE DISTURBING CONDITIONS IN THE PRE-MARITAL RELATIONSHIP

The way in which the basic conditions operate to create a problem for the pre-marital group is seen from the frequency with which they give rise to the specific classes of immediate conditions. This is shown in Table 3.

If the attention is concentrated on the women for the time being, it will be noted that:

1. Among the women who regard social status and religion and nationality as basic disturbing conditions, the majority report parental attitude as the immediate disturbing element. Principles is the next most frequent immediate condition.

2. Of the women who complain of the inadequate income of the male, the highest percentage finds parental attitude to be the immediate obstacle. Slightly lower is the percentage of women for whom marriage needs is associated with this basic condition.

3. When temperamental traits, marital status and sexual behavior are the basic conditions, the majority of the women regard affection as the immediate disturbing condition. Second in order of frequency appears principles.

4. The highest percentage of those giving age as the basic disturbing element also regard affection as the immediate obstacle; but next in frequency is parental attitude.

5. Cases of social vices on the part of the prospective husband are in the majority associated with marriage needs as the stated immediate condition.

TABLE 3

Percentage of women and men with given basic conditions who report specified immediate disturbing conditions in the pre-marital relationship

BASIC CONDITIONS	PERCENTAGES OF IMMEDIATE CONDITIONS					
	Affection	Parental attitude	Principles	Marriage needs	Total	Number of cases
			Women			
Temperamental traits	88.0	...	12.0	...	100.0	25
Marital status	52.9	20.6	26.5	...	100.0	34
Sexual conduct	51.0	11.8	23.5	13.7	100.0	51
Age	42.9	37.1	20.0	...	100.0	35
Somatic peculiarities	40.0	...	20.0	40.0	100.0	5
Inadequate income (male)	21.7	34.8	15.2	28.3	100.0	46
Social status	18.6	54.3	24.3	2.9	100.1	70
Social vices	5.9	17.6	17.6	58.8	99.9	17
Religion and nationality	4.8	61.9	23.9	9.5	100.1	42
Kinship	...	25.0	62.5	12.5	100.0	8
Total	32.7	33.3	22.2	11.7	99.9	333
			Men			
Temperamental traits	66.7	...	22.2	11.1	100.0	9
Marital status	20.0	...	80.0	...	100.0	5
Sexual conduct	40.9	...	31.8	27.3	100.0	22
Age	54.5	18.2	27.3	...	100.0	11
Somatic peculiarities	40.0	40.0	20.0	...	100.0	5
Inadequate income (male)	21.4	14.3	14.3	50.0	100.0	14
Social status	27.3	45.5	21.2	6.1	100.1	33
Social vices	...	...	...	...	....	..
Religion and nationality	20.0	53.3	26.7	...	100.0	15
Kinship	...	...	100.0	...	100.0	3
Total	33.4	24.8	28.2	13.7	100.1	117

6. Principles is the immediate condition most often found when kinship is the basic condition.

In general and with due regard to the size of the sample, similar findings are to be observed for the men. The only exceptions seem to be:

1. When marital status is the basic condition the men record principles as the most frequent immediate condition, while for the women this is affection.

2. Among the men, marriage needs is the immediate condition most frequently found associated with the class of inadequate income but for the women it is parental attitude.

From these observations a fairly definite picture is obtained regarding the manner in which those qualities, here termed basic conditions, come to be regarded as obstacles to the formation of the marital group. Differences in social status, religion, and nationality become basic disturbing conditions mainly because of parental opposition. Relatively few of the men and women of this sample attempt to evaluate the superiority of certain theological principles and doctrines and even fewer are preoccupied by theories of social caste and racial differences. At the most, when abstract principles are introduced, they are expressed by the consideration of "what people will say." The deference to the parents' wishes, as has been said, derives from the fact that the subjects are dependent at present or they do not visualize complete independence in the future from the support, financial or otherwise, of the parents. In this respect, a difference between the men and women of this sample is to be noted. The men postulate parental attitude as an immediate disturbing condition less often than do women. This is particularly true when the basic condition is the inadequate earning capacities of the male. For this condition, the men, and to a lesser degree the women, demonstrate a clearer understanding of its consequences since they regard it as an obstacle to marriage mainly because the practical needs of married life will thus not be satisfied. A relatively large percentage of the women also realize this but the majority refer to parental attitude as the immediate condition.

A different type of attitude is noted when the other persons have disagreeable temperamental traits, or they are already married, or they manifest a promiscuous sexual conduct. These qualities apparently become disturbing conditions mainly because they may bring about a change in the mutual affective relations and therefore hinder the mar-

riage. Here one notes a view of the situation which is primarily pragmatic. For the majority of these men and women the relationship established with a person still married is not apparently preoccupying relative to its legal or moral aspects. The main problem is whether he or she is to be trusted to go through the divorce proceedings and to keep the promise of marriage. The same general attitude is typical when the basic conditions are age, temperamental traits, and promiscuous sexual behavior. Apparently only a small minority consider these qualities of the partner from the standpoint of the future happiness of marriage. In particular, with regard to the sexual behavior, which is an important category numerically, the outcome most frequently feared is that he or she will drift into other relationships. Incidentally, it should be realized that the findings on the men imply that the majority of them are not worried by the lack of virginity in the future spouse.

Among the least frequent basic conditions, the habits of gambling and excessive drinking in the man are considered as obstacles to marriage mainly because the women believe that such men will probably not supply the necessary material comforts after marriage. On the other hand, the difficulty that arises when cousins desire to marry involves primarily moral and religious ideas.

On the whole these data seem to indicate that the general social qualities of an individual become disturbing conditions when they run counter to the ideas and beliefs of the parents. Personal behavioristic traits also acquire the properties of disturbing elements when apparently they entail the risk of a change in affection before marriage. These observations suggest that in general the characteristics of an individual may come to be regarded as disturbing conditions in the pre-marital relationship because they serve to create an imminent and tangible risk to the possibility of marriage. Such evaluation of the consequences of these characteristics derives from considerations which do not reflect either on the intrinsic nature of the traits, or on their importance with respect to marriage.

SUMMARY AND DISCUSSION

This is the report of an analysis of the basic and immediate conditions which adversely affect the pre-marital relationship of 333 women and 117 men. The mean age of the women is 21 years and of the men, it is 25 years. The pre-marital relationship has been maintained for over 3 years on the average.

The study reveals:

1. Differences in the social status, religion and nationality of the two partners, the promiscuous sexual conduct of the other partner, and the inadequate income of the man constitute the basic conditions which disturb the pre-marital relationship of about 70 percent of these men and women. Differences relating to other personal traits are noted less often. There is a close similarity between the men and women with respect to the order of frequency of the basic conditions.

2. The immediate disturbing condition most frequently noted in the sample of women is parental opposition. Next in order of frequency is the fear of a change in affection between the partners. This latter condition is the one which is regarded as immediately disturbing by the highest percentage of men while violation of abstract principles preoccupies the second largest group. Among both men and women a consideration of the needs of married life preoccupies the lowest number of persons.

3. Differences relating to general social traits — social status, religion, nationality, income — become basic disturbing elements primarily because of parental opposition. Behavioristic and personal traits such as age, marital status, temperamental traits and promiscuous sex conduct of the other partner are regarded as factors hindering the marriage because it is thought that they might produce before the marriage a change in the affective relations between the two persons. Gambling and excessive drinking on the part of the man are regarded as basic disturbing conditions mainly because it is feared that as a consequence the marriage needs will not be satisfied. The existence of close blood ties between the man and woman is the sole condition that becomes an obstacle to marriage primarily because of the moral principle and social sanctions involved.

From these observations conclusions may be drawn relative to the specific problem of marriage as well as to the general problem of social groupings.

The problems which vex these couples originate essentially from social and personal differences between individuals. These differences do not affect the development of a mutual emotional attachment and are outside the sphere of action of the primary sexual selection. This is so because these differences, on the whole, reflect individual variations in qualities which first of all are not essential to mating and, secondly, represent concepts derived from superorganic manifestations. As a

consequence, in addition to the primary sexual selection other mechanisms are introduced to regulate the formation of the marital group.

From these data it appears that a certain degree of homogamy with respect to the superorganic variables is attained principally by the operation of factors of immediate practical significance, or regarded as such, rather than by the abstract principles which theoretically are conceded to be the permissible limits of variability in individual behavior. When the differences between the two individuals are constituted by traits subject to social sanctions, this is disregarded by the majority who instead are interested in whether the trait may not interfere with the possibility of marriage. The most striking example of this is represented by the problem which arises from the relationship with a married person. The tabu occupies the thoughts of a minority of the women. The majority are interested instead in knowing whether he might not change his mind about divorcing the wife.

On the basis of the data presented it is apparent also that it is not because of tabus but because of active parental opposition that mesalliances and mixed marriages do not occur more often. Thus, the inadequate social conditioning of the individuals is reinforced by the realization of the immediate tangible fact that they will lose the practical support of the parents. Without entering into the merits of the parental attitude, its effectiveness cannot be denied. This has been made clear in the earlier study on the conflicts of married women. It was there shown that conflicts due to inadequate income of the husband, social status, nationality and religion were a minimum but those due to the conditions corresponding to promiscuous sexual conduct and temperamental traits definitely were the most frequent. This would seem to indicate that for those conditions about which the parental attitude is least concerned there arises the possibility of mismating from a social viewpoint. It is a situation to be expected since in the problem of marital selection there is always present the strong primary biological urge which apparently prevails even over the realization of the future practical needs of living.

From these observations it is apparent that the validity of some of the conclusions previously reached by the writer regarding social groups in general are sufficiently demonstrated. The study of the social organism, it has been said, reduces itself to a study of the individual and the elements that enter into the interaction between the individuals. Here it has been shown that the formation of a group, as well as its persis-

tence, is a function of the limits placed on the variability of individual traits, whether strictly personal or deriving from the other social groups to which the individual belongs.

In addition and deserving emphasis, it is to be inferred that, while formally elaborate concepts have been evolved to define these traits in relation to social behavior, actually and overtly they are determined by considerations of expediency that reflect elementary biological needs.

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————. 1938b. On human social biology. II. Disruptive and cohesive factors in the marital group. HUMAN BIOLOGY, Vol. 10, pp. 555-574. (The reader will find in this paper a list of the more important publications on the subject of marriage.)

PLACENTATION STUDIES: CORRELATIONS BETWEEN SIZE OF SAC, AREA OF PLACENTA, WEIGHT OF PLACENTA, AND WEIGHT OF BABY

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IN THE course of a series of studies undertaken to develop and confirm certain theories of the formation and growth of the human placenta, it became important to have first-hand knowledge of the relationships existing between the dimensions of the sac, placenta, and fetus. The methods used to obtain the measurements have been described by Torpin.* The present paper is a summary of the results obtained from a statistical treatment of the data, showing the relative presence or absence of interdependence between the various pairs of measurements.

The following data were collected on 216 childbirth cases in the University Hospital or under the supervision of the domiciliary obstetrical service. They are referred to throughout the mathematical treatment by the symbols indicated:

u = sac volume in cc.
w = placental weight in g.
y = placental area in sq. cm.
z = baby weight in g.

On the assumption that the shape of the sac is enough like a sphere to make little difference in relative figures, the following quantities were calculated from the sac volume:

r = sac radius in cm. $\left(\sqrt[3]{\frac{3u}{4\pi}}\right)$

x = sac area in sq. cm. $(4\pi r^2)$

* Torpin, R. Description of a new method of studying placentation by amniotic sac distention. *Am. Jour. Obs. Gyn.*, 35, 683-5 (1938).

Of the 216 cases, 26 were known to be premature births, while the rest were either stated or assumed to be full-term deliveries. Many of the data were not quite complete, decreasing the number of cases usable for some of the correlations, as indicated in the tables.

The mathematical treatment consisted of the following steps:

I. Calculation of the ratio $\frac{\text{placental area}}{\text{sac area}}$ and of the mean value of this ratio for prematures and for full terms.

II. Calculation of the mean and standard deviation for the distribution of each measured quantity.

III. Plotting of empirical regression lines.

IV. Calculation of total correlation and regression coefficients for each pair of data for the whole series and for prematures and full terms separately.

V. Calculation of partial correlation and regression coefficients for each pair of data for the whole series and for prematures and full terms separately.

RESULTS

The ratio $\frac{\text{placental area}}{\text{sac area}}$ was found to have a mean value of 0.248 ± 0.0025 for 145 full-term cases and 0.258 ± 0.011 for 23 prematures. There is thus seen to be little significant difference between the two groups in this respect. Correlation coefficients were not calculated between this ratio and the other measurements, but in view of theoretical developments to be presented elsewhere, it is interesting to note that the placenta covered, on the average:

29.0 per cent of sacs with areas less than 1000 sq. cm.
26.2 per cent of sacs with areas between 1000 and 1100
25.1 per cent of sacs with areas between 1100 and 1200
24.7 per cent of sacs with areas between 1200 and 1300
22.6 per cent of sacs with areas between 1300 and 1400
21.3 per cent of sacs with areas between 1400 and 1500
20.9 per cent of sacs with areas greater than 1500 sq. cm.

Table 1 gives the mean, with its standard deviation and the standard deviation of the series for each of the measured quantities. The first columns give the values for the maximum number of cases used; the

next columns, for the 164 cases whose data were complete; the last columns, for the premature and full-term cases separately. Each mean is rounded off at the place corresponding to the first significant figure of its standard deviation.

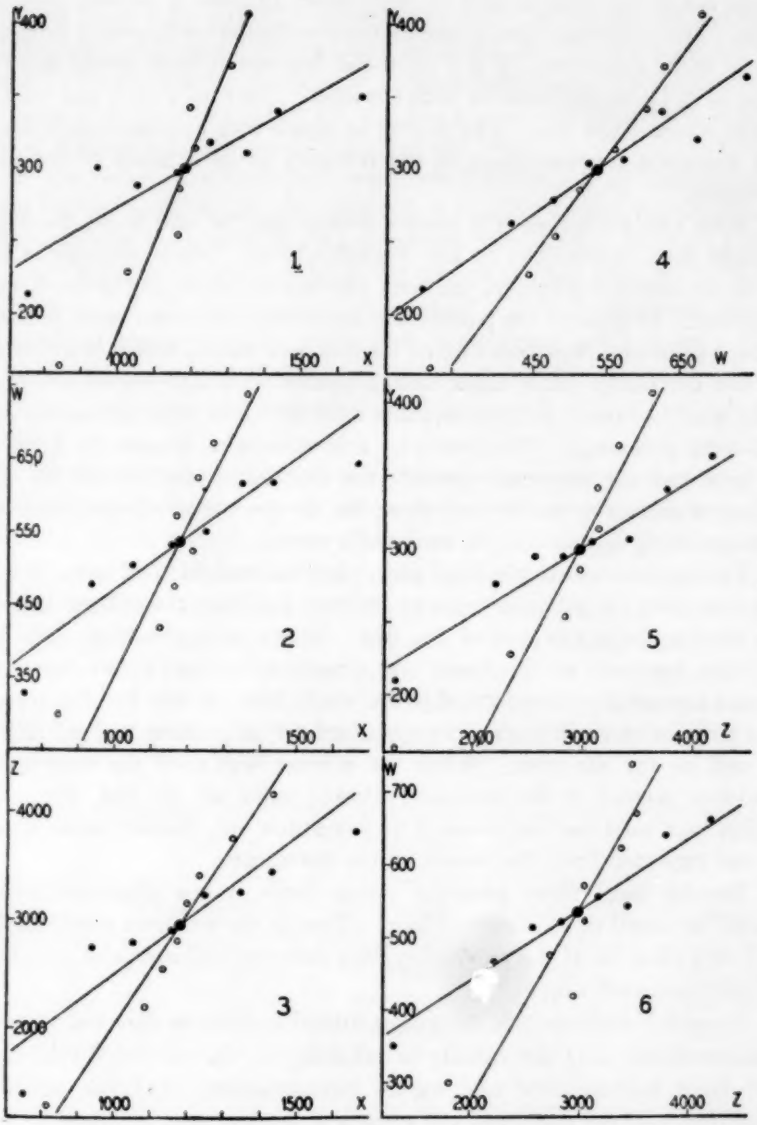
TABLE 1

Mean, with its standard deviation, and the standard deviation of the series for sac volume (u), sac area (x), sac radius (r), placental area (y), placental weight (w), and baby weight (z)

	WHOLE SERIES			164 CASES		19 PREMATURE		145 FULL-TERM	
	n	M and σ_m	σ	M and σ_m	σ	M and σ_m	σ	M and σ_m	σ
u (cc.)	...	.....	...	3850±71	912	2500±210	891	4030±62	750
x (cm.^{2})	209	1170±15	219	1180±15	194	870±53	223	1220±12	149
r (cm.)	...	.....	...	9.65±.07	.848	8.3±.27	1.16	9.83±.05	.592
y (cm.^{2})	202	297±4.1	58.2	300±4.5	57.5	230±13	56.1	309±4.2	50.2
w (g.)	209	530±8.7	126	536±9.3	119	380±32	136	557±8.4	101
z (g.)	179	2950±56	747	2970±55	699	1600±140	586	3150±40	483

Since the validity of the product-moment coefficient of correlation depends upon the rectilinearity of the regression lines, these were plotted directly from the data, with arbitrary origins chosen near the means of the four arrays. The cases were arranged, in turn, according to the size of each variable and were divided each time into eight groups. The groups were chosen to cover as nearly as possible equal ranges of the independent variable except near the extremes where several had to be combined to get fairly representative figures. For each of the four sets of groupings the means of the four measurements were calculated and the pairings thus obtained were plotted in Figs. 1-6. The lines of best fit were calculated and drawn in.

Three significant points appear from a study of the regression lines plotted in Figs. 1-6. Although there is a considerable scatter of the



FIGS. 1-6. REGRESSION LINES: (1) SAC AREA—PLACENTAL AREA; (2) SAC AREA—PLACENTAL WEIGHT; (3) SAC AREA—BABY WEIGHT; (4) PLACENTAL WEIGHT—PLACENTAL AREA; (5) BABY WEIGHT—PLACENTAL AREA; (6) BABY WEIGHT—PLACENTAL WEIGHT

Heavy circles, regression of ordinate upon abscissa. Hollow circles, regression of abscissa upon ordinate. Ringed circles at mean values of arrays.

points about the lines of best fit, there is in all cases a definite positive slope. The graphical significance of the correlation coefficient is brought out in these diagrams. For $r = 0$ the regression lines would have a slope of 0, i.e. would coincide with the axes. For $r = 1$ each pair would merge into a single line. The degree to which they approach each other is a graphical representation of the intensity of association of the two variables.

With two exceptions the plotted points may be said to be fitted by straight lines better than by any smooth curves. These exceptions involve the extreme points on the lines, particularly those in the lower left quadrant. In general the points near and above the mean seem to have a slope somewhat less than that of the line as a whole, which is weighted by the extremely small cases falling nearer to a 45° regression line. This was the reason for the separation of the cases into premature and full-term groupings. The result of this separation is seen in Table 2 to have had the expected results: the correlation coefficients for the full-term cases are smaller and those for the prematures larger than the corresponding figures for the series as a whole.

The regressions of placental area, placental weight, and baby weight upon sac area are all seen to have a definite tendency toward the axis of sac area at the upper end of the line. Taken in conjunction with the opposite tendency at the lower end (mentioned above) this seems to impart a generally curved trend to the whole line. It was for this reason that correlation coefficients were calculated for sac volume and sac radius as well as for sac area. When the volume was used the curvilinear tendency seemed to be increased (lower value of r) and when the radius was used the line seemed to straighten out (higher value of r) as was expected from the nature of the curvature.

Besides these three principal points there is one observation that should be noted to be discussed later. That is the uniform rectilinearity and very close fit of the regression lines for placental area and placental weight upon each other.

In such a study as this, particular attention must be directed to three considerations: (1) the validity or reliability of the calculated statistics; (2) their mathematical and logical interpretation; (3) the practical significance of the analytical and graphical results taken together.

The reliability of the calculated constants is indicated in all tables by their respective standard deviations. These represent the limits within which about two-thirds of such values, calculated for additional samples

of the same size, would be expected to fall. In the case of correlation coefficients this range depends both upon the size of the coefficient itself and upon the size of the sample. The smaller partial correlation coefficients and those calculated for the small series of premature cases are seen to have a greater variability than the rest.

The correlation coefficient measures the intensity of association between two variables, or the range of variability within which the same value of one quantity is always associated with a given value of another. When this correlation is perfect the quantities vary directly ($r = +1$) or inversely ($r = -1$) with each other. The positive and negative values of the correlation coefficient range from unity down to zero, where there is no association at all, in which case high and low values of one variable are found associated indiscriminately with all values of the other.

In the case of perfect correlation between two variables ($r = +1$ or -1) a knowledge of one of them permits the exact prediction of the other. When there is no correlation the prediction is limited only by the scatter of all values of the second variable. The correlation coefficient furnishes an estimate of the gradual narrowing of the limits of scatter of the quantity to be predicted. It should be borne in mind, however, that this "prediction value" increases not linearly with r but

TABLE 2

Total correlation coefficients with their standard deviations for the four groups

	WHOLE SERIES		164 CASES	19 PREMATURE	145 FULL-TERM
r_{sy}	202	0.52±.052	0.48±.060	0.60±.15	0.23±.079
r_{sw}	209	0.66±.039	0.61±.049	0.75±.10	0.40±.070
r_{sz}	179	0.76±.032	0.71±.039	0.76±.10	0.48±.064
r_{ry}	...	.....	.....	0.66±.13	0.24±.079
r_{rw}	...	.....	.....	0.76±.10	0.41±.069
r_{rz}	...	.....	0.72±.037	0.90±.043	0.40±.070
r_{wz}	...	.....	0.69±.041	0.71±.11	0.48±.066
r_{yw}	199	0.74±.033	0.70±.040	0.80±.084	0.58±.055
r_{yz}	168	0.56±.053	0.56±.054	0.77±.096	0.29±.076
r_{wz}	176	0.68±.041	0.63±.048	0.70±.12	0.42±.069

very slowly at first. The scatter of one variable for a given value of the other is only 20 per cent less when r is .6 than when r is zero.

In so far as the value of one variable can be predicted from a knowledge of another, it may be inferred that a part of a system of causation common to the two (whether it be mutual or not) is defined by their correlation. Some limitations of this logic, however, will appear in the interpretation of the present results.

Table 2 shows the total correlation coefficients with their standard deviations (1) for the largest possible series of each pair, (2) for the 164 cases suitable for complete analysis, (3) for the 19 premature cases included in the 164, and (4) for the remaining 145 cases.

The authors believe that the results presented warrant the following conclusions. An attempt is made to adhere to the mathematically demonstrated facts without inferring from them any type of causation.

1. The total correlation coefficients show, as might be expected, statistically reliable and fairly close associations among the values of all four measurements taken in pairs.

2. These associations are more intense in the premature cases (also as might be expected during growth) than in the full-term cases, but unfortunately the small size of this series detracts from the precision with which the constants can be stated.

3. The closest association is between sac size and baby weight, followed closely by that between placental area and placental weight.

4. Except for the series of prematures, where the figures are not significantly different, the correlation between baby weight and placental weight is slightly better than that between baby weight and placental area.

5. For the series of 164 cases the baby weight is more closely correlated with the radius of the sac than with its area or volume. This implies an increase in fluid volume much more rapid than the increase in baby weight. Such a conclusion, however, is believed to be a mathematical artefact due to two conditions: (a) the inclusion of premature cases where it may indeed be true; (b) the inclusion of several full-term cases with very large sacs which were probably hydramnios and should not be thought of as members of a normal series.

So far only the total correlation coefficients have been considered — those which could have been obtained if only one pair of data had been available on each case. The possession of all four, however, permits a

more searching examination of the associations between the measurements. Table 3 shows what can be done if any three data are given for each case. For example, if sac area, placental area, and baby weight are known, not only can the correlation coefficients for each pair be calculated but from them an estimate can be made of the association of values of any pair for constant values of the third. It is of interest to know not only whether there is a correlation between sac area and placental area but also whether high values of one are consistently associated with either high or low values of the other for a constant baby weight.

The same reasoning applies to the partial correlation coefficients of the four variables taken together, except that here any two may be held constant and the association of values of the other two calculated for this condition.

Table 3 (a-d) shows the partial correlation coefficients of the four variables taken three at a time, representing the intensity of association of each pair when either of the other variables is held constant. The symbol $r_{xy.z}$, for example, stands for the coefficient of correlation between x and y when z is held constant. The calculations were made from the formula

$$r_{12.3} = \frac{r_{12} - r_{13}\, r_{23}}{\sqrt{(1 - r^2_{23})\ (1 - r^2_{13})}}.$$

The cases are given as before, as a whole and separately as premature and full-term cases.

The results tabulated here may be interpreted as follows. When any one variable is held constant the relative presence or absence of interdependence between any two others is shown more clearly, though the absolute values of all the correlation coefficients are somewhat lower.

1. With baby weight constant there is no significant correlation between sac area and placental area for premature, full term, or all cases. There is a small but significant correlation between sac area and placental weight and a fairly strong association between placental area and placental weight. For the last of these three the coefficient is both larger and more reliable for the full term than for the premature cases, while for sac area-placental weight the coefficient is greater but less reliable for the prematures.

2. With placental weight constant there is no significant correlation between sac area and placental area for any group. There is a strong

TABLE 3

Partial correlation coefficients of the four variables taken three at a time, representing the intensity of association of each pair when either of the other variables is held constant

		164 CASES	19 PREMATURE	145 FULL-TERM
(a)	$r_{xy.z}$	0.14±.076	0.05±.23	0.11 ±.08
z	$r_{xw.z}$	0.30±.071	0.47±.18	0.25 ±.078
constant	$r_{yw.z}$	0.54±.055	0.46±.19	0.53 ±.060
(b)	$r_{xy.w}$	0.10±.078	0.01±.24	0.004±.08
w	$r_{xz.w}$	0.53±.056	0.49±.18	0.37 ±.072
constant	$r_{yz.w}$	0.22±.075	0.49±.18	0.07 ±.08
(c)	$r_{xw.y}$	0.44±.064	0.55±.16	0.33 ±.074
y	$r_{xz.y}$	0.60±.050	0.57±.16	0.44 ±.067
constant	$r_{wz.y}$	0.40±.066	0.21±.22	0.32 ±.075
(d)	$r_{yw.x}$	0.59±.051	0.66±.13	0.55 ±.058
x	$r_{yz.x}$	0.35±.069	0.60±.15	0.22 ±.079
constant	$r_{wz.x}$	0.35±.069	0.30±.21	0.29 ±.076

association between sac area and baby weight for the whole series, while the value for prematures is higher but less reliable than for the full terms. There is a slight correlation between placental area and baby weight which is due entirely to the premature cases.

3. If placental area is held constant there is a good correlation between sac area and placental weight — again, higher but less reliable in the series of prematures. The correlation between sac area and baby weight is good and reliable for all three groupings. The correlation between placental weight and baby weight is insignificant in the prematures but is definite, though slight, in the full-term cases.

4. If sac area is held constant there is a very good and significant correlation between placental area and placental weight in all three groupings. The correlation between placental area and baby weight is significant but not great. The correlation between placental weight and baby weight is also slight and, except for the prematures, significant.

Table 4 gives the partial correlation coefficients of the four variables taken together, representing the intensity of association of each pair when the other two variables are held constant. The symbol $r_{xy.wz}$, for

example, stands for the coefficient of correlation between x and y when both w and z are held constant. The cases are given as a whole series and as premature and full term separately.

TABLE 4

Partial correlation coefficients of the four variables taken together, representing the intensity of association of each pair when the other two variables are held constant

	164 CASES	19 PREMATURE	145 FULL-TERM
$r_{xy.wz}$	0.02±.078	0.30±.21	0.02±.083
$r_{xw.yz}$	0.26±.073	0.55±.16	0.22±.079
$r_{xz.yw}$	0.52±.052	0.56±.16	0.37±.072
$r_{yw.xz}$	0.53±.052	0.63±.14	0.51±.061
$r_{yz.xw}$	0.20±.075	0.55±.16	0.07±.083
$r_{wz.xy}$	0.19±.076	0.16±.23	0.21±.080

When two variables at a time are held constant there are only two combinations that stand out as being closely associated with relative independence of the others. These pairs are sac area-baby weight and placental area-placental weight. Among the prematures the sac area-placental weight and placental area-baby weight figures are also high but they have not quite so narrow precision limits. Among the full-term cases the placental area-placental weight correlation is the only one that is definitely high. The sac area-baby weight figure represents a significant correlation but not so intense.

The high correlation between sac area and baby weight, persisting no matter what other measurements are constant, is to be expected; except for variations in relative hydramnia and anhydramnia, the sac should be expected to increase with the size of the baby.

Nor is the consistently high correlation between placental area and placental weight surprising. As the placenta increases in area it increases in weight. The inference to be drawn is that increases in weight are brought about, in the long run, not by increases in thickness. Indeed, when the exceptionally good fit and rectilinearity of the regression lines are considered, the conclusion seems justified that after reaching a

certain thickness the placenta tends to increase in size much more by increase in area than by any further increase in thickness.

In conclusion, the results of this analysis point to the limitations within which the causal factors underlying baby, sac, and placental growth can be stated. Particularly they offer a warning against the use of single total correlation coefficients in attempts to bring those factors to light.

STUDIES ON PUPILS OF THE PENNSYLVANIA SCHOOL FOR THE DEAF
2. RESEMBLANCES IN THE AUDITORY ACUITY OF SIBLINGS[1]

BY ANTONIO CIOCCO, WALTER HUGHSON, AND CARROLL PALMER

INTRODUCTION

THE importance of the biological constitution relative to auditory acuity is being recognized more and more as further information on pathological variation in hearing is accumulated. It is generally accepted that heredity is a factor in the occurrence of deaf-mutism, otosclerosis, and Manasse's type of labyrinthine deafness.

Lenz (1931) estimated that in Germany about 30 per cent of deaf-mute cases are inherited. Attention was first drawn to the familial concentration of this disease by the studies of Alexander Graham Bell (1883) and by those of Fay (1898). Additional evidence on this point has been given by the frequency with which deaf-mutes spring from consanguineous marriages, as noted by Hanhart (1924), Richardson *et al.* (1928), and many others. Finally, from the pedigrees reported, especially those published by Love (1896) and by Albrecht (1922), the majority opinion is that the inheritance of deaf-mutism follows a Mendelian scheme and is transmitted as a simple recessive factor. Some objections have been raised regarding this conclusion lately by Kraatz (1925) who thinks that the inheritance of this condition is due to two, not one, recessive factors. The controversy on this point apparently

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[1] From Child Hygiene Studies, Division of Public Health Methods, National Institute of Health, U. S. Public Health Service; the Department of Biology of the Johns Hopkins School of Hygiene and Public Health; and the Otological Research Laboratory of the Abington Memorial Hospital.

The first of this series entitled: Auditory acuity, by W. Hughson, A. Ciocco and C. Palmer, appeared in *Archives of Otolaryngology* (1939).

results from the lack of a criterion to distinguish genotypic from phenotypic deaf-mutism.

With regard to otosclerosis, Toynbee's (1860) observations were the first to indicate clearly that it is a familial disease. That this condition is inherited has been confirmed by the careful studies of Körner (1905), Hammerschlag (1905), Albrecht (1922), Davenport and associates (1933) and numerous others. However, there is very little agreement about the mode of transmission. One of the latest hypotheses is that advanced by Davenport *et al.* who think that otosclerosis is due to the concurrence of two dominant genes, one in the X-chromosome and the other in an autosomal chromosome.

The labyrinthine deafness described by Manasse is another defect for which heredity is regarded as mainly responsible. Bauer and Stein (1926), who have collected data on this condition, believe that three recessive genes are responsible for its transmission. Incidently, these authors believe that the three defects — deaf-mutism, otosclerosis, and labyrinthine deafness — are simply different aspects of a developmental inferiority of the organ of hearing. However, sufficient evidence to sustain this view has not been advanced.

In other respects, besides the specific inheritance of types of auditory defects, there are manifestations which point to the importance of the constitutional factors in matters regarding the anatomy, physiology, and pathology of the ear. Thus, the relation of the shape and size of the Eustachian tube, the development of the mastoid process and the shape of head and face to the incidence of middle ear infections has been indicated. From the findings of Prekalin (cf. Albrecht, 1931) and those of Ciocco (1933), it appears that these infections occur more frequently in brachycephalic individuals and in those with round and square faces. The explanation for this seems to be that an aerogeneous infection is more readily possible in persons with relatively short heads and broad faces since, according to Pautow (cf. Albrecht, 1931), the Eustachian tube tends to be short and wide in such individuals. Moreover, associated with this form of head and face is also a relatively underdeveloped mastoid process which, according to Wittmack (1918) provides an environment that favors acute inflammation. This is a fact confirmed by Skoog (1932), who also has reported that in middle ear infections there is some specific association between type of bacteria and degree of mastoid pneumatization.

In the case of high tone loss, one notes that there is a sex, racial, and somatological factor associated with its incidence. Bunch and Raiford (1931) first observed the greater frequency of high tone loss in adult males than in adult females and among white persons as compared with Negroes. Ciocco (1932, 1936, 1937) extending the observations on the sex difference to children, found this greater frequency of high tone loss in males even before the age of puberty. Ciocco (1933) also presented evidence that this defect is more frequent in the asthenic type of body build. However, no explanation of these findings has yet been presented.

From the observations summarized above, it would seem that the influence of constitutional factors in the development of the organ of hearing is demonstrated, especially with respect to the incidence of auditory defects, and can be determined quantitatively to some degree. In view of this, and since the anatomical and pathological conditions of the organ of hearing are associated with the hearing function itself, it may be asked whether the effect of constitutional elements is not also apparent in auditory acuity. A first attempt to answer this question is reported in this paper, which presents the results of a study on deaf children to determine if the auditory acuity has greater or less resemblance between siblings than between children who are not blood relatives.

MATERIAL

The material on which this analysis is based was obtained from the records of a hearing survey made in 1938 at the Pennsylvania School for the Deaf. At that time the auditory thresholds of 487 children were measured for both air and bone conduction with a Sonatone Model 1 audiometer. This instrument, like others of its kind, is a vacuum tube oscillator equipped to produce tones of several fixed frequencies at measurable intensities. In this case the tonal frequencies tested were the seven octaves from 128 to 8192 cycles. The intensity of the sound produced is measured in decibels. The results of those examinations, and the auditory characteristics of the children, have been described by Hughson *et al.* (1939). Among the children there were 40 pairs of siblings. The records of the siblings constitute the nucleus of the material here analyzed.

In 28 pairs (70 per cent) both siblings were said to have been born deaf. In three cases, the two siblings were made deaf by the same disease — meningitis was the stated cause for one pair and whooping

cough for the other two. In total, then, the stated causes of deafness was different in the two siblings for only 9 of the 40 pairs. Similarly, the age of onset of deafness was different in the two siblings for only 9 pairs. In this respect the greatest difference between the ages of onset was 4 years, and it was observed for 3 pairs of siblings. It may be added that on the average there is a difference of 3½ years between the older and the younger.

As a control group with which to compare the differences in hearing between siblings, the records of 40 other children were selected from the total material collected. Since the selection constitutes an integral part of the method of analysis, it will be discussed in the following section.

Method of analysis

This analysis consists simply of a direct comparison between two sets of differences in auditory acuity. The first set is made up of the differences in auditory thresholds between siblings; the second, those observed in pairs of non-siblings selected in the manner noted below. The choice of the procedure employed here has been determined largely by the characteristics of the material. These are the records of deaf children and the auditory thresholds are concentrated close to the maximum intensity of sounds possible for this instrument. Consequently, since the distribution of threshold responses to any particular tone takes the form of a J-shaped curve, the classical correlation technique is not valid. The method used also has certain inherent advantages which will be shown later.

The following were the steps taken in the analysis: Each pair of siblings was separated into older and younger member. For each tone tested and for the right and left ear, respectively, the threshold found for the younger sibling was subtracted from the threshold found for the corresponding ear of the older sibling. For each tone, then, the mean of these 80 differences constitutes the average difference in auditory acuity between siblings. An estimate of the significance of these differences between siblings can be obtained by comparison with the differences found between pairs of non-siblings.

The usual procedure would be to select, at random, pairs of children differing in age, sex, and other characteristics as the siblings do among themselves, and to note the differences in their auditory thresholds. By so doing, however, it is rarely possible to control all the variables so that the pairs of siblings and the pairs of non-siblings are comparable.

Therefore, to reduce the probable influence of extraneous elements, in this study the control pair differences have been secured from the differences between the auditory thresholds of the older member of the sibling pair and those of another child selected at random but having the same age and sex as the younger sibling. Thus, one set of factors has been kept constant, and, it is believed, added value is given to the comparison. The results of this study will indicate whether, on the average, the auditory acuity of one group of deaf children differs from that of their older siblings to a greater or less degree than does that of another group of unrelated children.

The actual procedure in selecting the control children has been the following: The records of the younger siblings were arranged according to sex and age in single years. Starting with the record of the youngest boy, the files were searched in alphabetical order until a record was found corresponding to a boy of the same age as the child in question. The record thus selected was then paired with that of the older sibling. This process was repeated for each of the other younger siblings until all 40 controls were selected. It is felt that by this procedure a sufficient degree of randomness has been attained.

For each of the "control" pairs the differences in auditory thresholds were computed thereafter in the same manner as for the siblings.

DIFFERENCES IN AUDITORY THRESHOLDS BETWEEN SIBLINGS AND BETWEEN NON-SIBLINGS

For each tone tested, the average of the algebraic differences between the auditory thresholds of each pair of siblings and that of each pair of non-siblings are presented in Table 1.

From this table the following facts may be noted:

1. For all tones and for both groups, the average differences are positive.

2. For each tone, the numerical value of the average differences is lower for the siblings than for the non-siblings.

3. The standard deviation of the differences is consistently lower for the siblings than for the non-siblings.

Since the means of the differences in auditory thresholds are all positive it indicates that on the average the younger children show a lower degree of hearing impairment. It must be noted at this point that while all the mean differences for the non-siblings deviate significantly

TABLE 1

Means and standard deviations of the algebraic differences in auditory acuity between 40 pairs of siblings and between 40 pairs of non-siblings

TONAL FREQUENCY (*in cycles*)	MEAN OF DIFFERENCES (*in decibels*)		STANDARD DEVIATION OF DIFFERENCES (*in decibels*)	
	Between siblings	Between non-siblings	Between siblings	Between non-siblings
128	3.00 ± 1.28	8.81 ± 1.69	17.02 ± .91	22.45 ± 1.20
256	3.13 ± 1.13	5.44 ± 1.65	17.45 ± .95	21.85 ± 1.17
512	3.69 ± 1.16	5.88 ± 1.54	15.41 ± .82	20.45 ± 1.09
1024	2.19 ± .99	6.06 ± 1.46	13.08 ± .70	19.31 ± 1.03
2048	3.94 ± 1.24	5.25 ± 1.46	16.39 ± .87	19.31 ± 1.03
4096	3.75 ± 1.10	6.69 ± 1.12	14.57 ± .78	14.87 ± .79
8192	2.75 ± .65	5.69 ± .85	8.55 ± .46	11.31 ± .60
Number of ears	80	80	80	80

from zero, this is not always the case for the siblings. In view of these findings the conclusion reached by Hughson *et al.* (1939) regarding the relation of age to degree of impairment may have to be modified. At that time, from a comparison of the median auditory thresholds among children of diverse ages, no statistically significant difference was observed and it was inferred that in these deafened children the hearing impairment is not progressive. According to the present analysis, by a method which may be more appropriate, an age effect is noted. On the other hand, it is necessary to recognize that the number of cases covered in the present study is small.

The greater absolute variability of the differences between non-siblings is the first indication that siblings diverge less in auditory acuity than do non-related children. The standard deviation of the differences between non-siblings is over 5 decibels higher for the lowest tones tested, but comes closer in value to that between siblings for the highest tones tested. In this respect it is of interest to compare the standard deviations shown in Table 1 with those referring to the differences between the repeated tests made on a group of Washington, D. C. school children

TABLE 2

Standard deviation of differences between auditory thresholds at first and second test. Both ears of 543 children re-examined after an average interval of three years

(From Ciocco, 1937)

TONAL FREQUENCY (*in cycles*)	STANDARD DEVIATION (*in decibels*)
128	5.28 ± .29
256	5.18 ± .26
512	4.75 ± .26
1024	5.37 ± .29
2048	6.05 ± .33
4096	7.89 ± .41
8192	8.56 ± .44

after an average interval of 3 years. The standard deviations of the individual differences are shown in Table 2.

The data in Table 2 are based on 1086 ears, but the probable errors of the sigmas have been computed for 80 ears in order to give a correct idea of the deviations expected with a smaller sample. Comparing Table 2 with the corresponding information shown in Table 1, two important facts emerge:

1. The three groups of sigmas diverge from each other most for the low tones and least for the high tones. It is seen that for the tone of 128 cycles the values of the standard deviation range from 5.28 to 22.45 db., for the tone of 256 cycles they go from 5.18 to 21.85 db. On the other hand, for the tones of 4096 and 8192 cycles, the range is equal only to 6.98 and 2.76 db., respectively. This can be interpreted to mean that the threshold responses to low tones are less susceptible to the influence of factors which give rise to individual variability, and therefore have greater significance in the study of individual differences.

2. Between siblings the variability of the differences is greater than between repeated tests on the same individual made after an interval of about the same length of time as that of the age differences between siblings. In turn, the variability of the differences between siblings is less than that between non-siblings.

This finding is in accordance with expectations that the same factors operate for a pattern of auditory acuity as for, let us say, physiognomy. For example, it is expected that a person will resemble his portrait taken three years before much more closely than he will resemble a younger brother three years his junior.

In Table 1 the resemblance between siblings when compared to non-siblings is shown by the fact that for all tones tested the average of the differences between siblings is consistently lower by 1 to 5 decibels than the average between non-siblings. Thus it is seen that the older siblings, because of their relative age, have a greater hearing impairment than their younger brothers and sisters, but not as much as they demonstrate when compared to other children having the same age and sex characteristics of their younger siblings.

A clearer view of the significance of the findings in Table 1 is obtained when the absolute, instead of the algebraic, differences between thresholds are employed. A direct comparison of the means of the differences calculated in this fashion and shown in Table 3 will indicate more specifically whether the auditory thresholds of siblings are closer to each other than those between non-siblings.

The conclusion which was inferred from the data shown in Table 1 receives additional support from Table 3. It is seen that for all tones

TABLE 3

Arithmetic means of the absolute differences in auditory acuity between 40 pairs of siblings and between 40 pairs of non-siblings

TONAL FREQUENCY (*in cycles*)	MEAN OF DIFFERENCES (*in decibels*)	
	Between siblings	Between non-siblings
128	13.13 ± .85	18.06 ± 1.21
256	12.88 ± .92	16.44 ± 1.16
512	11.94 ± .79	15.75 ± 1.08
1024	10.06 ± .65	15.31 ± 1.00
2048	11.19 ± .95	15.00 ± 1.01
4096	8.88 ± .94	11.19 ± .90
8192	4.13 ± .60	6.94 ± .80
Number of ears	80	80

the average of the differences between the auditory thresholds of siblings is smaller than that between non-siblings. Moreover, the divergence between two corresponding means is probably not due to chance since it is over three times its probable error for the tonal frequencies of 128 and 1024 cycles, and over two and one-half times for the remaining tonal frequencies — except that of 4096 cycles, for which it is over twice its probable error. From these data the conclusion seems justified that between siblings there is less difference in auditory thresholds than between unrelated children.

In conclusion, the results of this analysis appear to indicate that among deaf children (so-called deaf-mutes) there is a certain amount of resemblance in the pattern and degree of auditory impairment. The significance of this finding would seem to be that it amplifies and extends those observations which indicate that constitutional factors determine the liability of the auditory system to maldevelopment or degeneration. Since the size of the sample is neither very large nor the material completely homogeneous, this conclusion can only be tentative. Nevertheless, these findings are consistent with what is known about the rôle of the constitutional factors on the auditory system as well as the evidence regarding the association between the pathology and the function of the ear.

In closing it may be added that so far as the authors are aware this is the first time that a fraternal resemblance has been shown for such finely differentiated functional characteristics as the degree of auditory acuity.

SUMMARY

A comparison has been made of (1) the average of the differences in auditory acuity between 40 pairs of siblings, and (2) the average of the differences between 40 pairs of unrelated children. On the whole, the analysis reveals that auditory acuity differs to a significantly less degree between siblings than between non-siblings.

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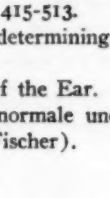

BODY BUILD IN INFANTS. IX. BODY BUILD IN ECZEMA

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THAT constitution is a factor in the etiology of eczema in infants was suggested by Czerny (1) who pointed out a relationship to the "exudative diathesis", and by Finkelstein (2) who speaks of body build characteristics in eczema similar to those found in infants with tetany, an observation which we have been able to confirm by quantitative methods (3).

In 1931 (3) we described changes in the body configuration of a group of 59 infants with eczema. They were shown to have, on the average, wider faces, broader shoulders and hips and larger chests, in relation to their height, than did healthy children from the same social economic environment. In the present report these results are confirmed and amplified. Larger series of both eczematous and control infants have been used and a larger number of dimensions studied.

METHODS

The method ordinarily used for studying body build differences between various groups consists of a comparison of the means for certain body dimensions and a statistical evaluation of the significance of any differences found. This method is not well suited to the study of body build in disease during childhood because of the changes in body proportions which occur with growth and, consequently, the necessity of dividing up the material into age groups. Since large numbers of infants with a particular ailment are ordinarily difficult to obtain, dividing the data in this way reduces the number of cases in each group to such an extent that the calculated means are of little significance.

In the present study the chi-square method (4) which permits the grouping of children of different ages and of both sexes was used for analyzing the data.

Growth curves were constructed for the various dimensions in the usual way. Fig. 1 contains, in addition to the average growth curve represented by a continuous line, 2 dotted lines which are, respectively, one standard deviation above and one standard deviation below the average. These curves are based on measurements made on a "control" group to be described presently.

In both figures, infants with eczema were spotted at the appropriate age and size of dimension. By application of the chi-square method, the reliability of deviations in distribution of the spots can be tested. The symbol used to express reliability in this instance is P. When P is less than .02 a statistically reliable difference may be said to be present.

The control group consists of 775 infants, of whom 433 were males and 342 females. The nationalities are mixed but only white infants are included. The group is a low income one. The infants were admitted to Bellevue Hospital as healthy boarders or because of mild upper respiratory infections and had received no regular medical supervision before admission.

The eczema group consists of 130 infants, of whom 90 were males and 40 females. Only infants with typical facial eczema are included. The national grouping of the infants, as nearly as could be determined, was similar to that of the control group. All infants were obtained from the wards or Out Patient Department of Bellevue Hospital and came from the same social economic environment as the control group.

The dimensions measured and the anthropometric technique have been described elsewhere (5).

Sex

The preponderance of males among infants with eczema is striking. In the series of Tisdall, Brown and Kelly (6), of Greenberg (7) and the present series summarized in Table 1 there were approximately twice as many males as females and this relationship is not significantly altered when correction is made for the ratio of males to females at birth which is 106 to 100. That this is not due to greater vulnerability of the skin in males in indicated by the fact that impetigo, the next most frequent skin disease of infancy, occurs with equal frequency in boys and girls (46 cases in males, 43 in females, Bellevue Hospital, 1935-1937). The greater susceptibility of male infants to eczema is of especial interest because of the relationship of this condition to allergy.

TABLE 1

The distribution of infants with eczema by sex

AUTHOR	NUMBER OF CASES			PERCENTAGE OF CASES	
	Total	Males	Females	Males	Females
Tisdall (6)	83	52	31	63	37
Greenberg (7)	61	43	18	70	30
Authors	130	90	40	69	31
Total	274	185	89	68	32

RESULTS

The chi-square distribution of 31 external dimensions in the infants with eczema is compared with the control group in Table 2. The distribution for weight is illustrated in Fig. 1.

Infants with eczema are, on the average, slightly but significantly taller than the control group but there is no significant alteration in the sitting height or the length of the lower extremities. The span length is also increased. This is due to the broader shoulders, the length of the upper extremities being unchanged. Infants with eczema are, on the average, considerably heavier than the control group. The deviation in weight is probably more marked than that found, since many of the measurements were made after the infants had been subjected to dietary restriction.

The head is larger and broader than in control infants of the same age. There is no change in the anteroposterior diameter of the head. The face is unaltered in height but is strikingly broader in both the bimalar and bigonial diameters than in the control infants. This increased facial width is evident clinically. We do not believe that the edema and induration over the malar eminences in infants with eczema interfere sufficiently with the accuracy of measuring to account for the amount of increase observed. The distance between the eyes (the interinner canthus diameter) is also wide, but the length of the palpebral fissure and the breadth of the nose are unchanged. The height of the lower jaw is greater than in control infants. The shoulders, hips, and chest circumference are larger on the average, than in the control infants. The hands and feet are also broad.

TABLE 2

The chi-square distribution of 31 external dimensions in infants with eczema

[A represents the number (children with eczema) which is more than one standard deviation above the mean; B represents the number which is less than one standard deviation above the mean; C represents the number which is less than one standard deviation below the mean; and D represents the number which is more than one standard deviation below the mean. Differences are significant when P is less than .02]

DIMENSION P		TOTAL	MALES	FEMALES	DIMENSION P		TOTAL	MALES	FEMALES
Total body	A	18	12	6	Bigonial	A	45	31	14
length	B	62	42	20	diameter	B	40	31	9
$P = .007$	C	34	25	9	$P = .000$	C	28	16	12
	D	16	11	5		D	12	8	4
Sitting height	A	19	12	7	Upper facial	A	18	10	8
	B	49	37	12	height	B	45	33	12
$P = .17$	C	42	30	12	$P = .80$	C	42	31	11
	D	13	6	7		D	24	15	9
Body weight	A	46	30	16	Length of palpe-	A	24	12	12
	B	43	36	7	bral fissure	B	45	36	9
$P = .000$	C	30	18	12	$P = .048$	C	44	32	12
	D	11	6	5		D	15	8	7
Length of	A	21	10	11	Inter-inner can-	A	39	29	10
span	B	59	43	16	thus diameter	B	52	35	17
$P = .007$	C	33	26	7	$P = .000$	C	30	19	11
	D	13	6	7		D	7	5	2
Circumference	A	35	23	12	Breadth of	A	18	15	3
of head	B	41	28	13	nose	B	50	39	11
$P = .006$	C	31	22	9	$P = .57$	C	39	25	14
	D	19	13	6		D	23	11	12
Cephalic	A	22	15	7	Height of	A	19	12	7
length	B	48	31	17	nose	B	47	31	16
$P = .80$	C	43	30	13	$P = .027$	C	31	21	10
	D	18	14	4		D	32	25	7
Cephalic	A	37	27	10	Height of	A	38	25	13
breadth	B	45	28	17	lower jaw	B	39	26	13
$P = .002$	C	35	27	8	$P = .000$	C	43	34	9
	D	14	8	6		D	8	3	5
Diameter of face	A	60	47	13	Length of	A	35	28	7
(bimalar)	B	37	23	14	ear	B	40	27	13
$P = .000$	C	24	13	11	$P = .016$	C	35	23	12
	D	6	4	2		D	20	12	8

TABLE 2 (*continued*)

DIMENSION *P*		TOTAL	MALES	FEMALES
Breadth of ear	A	20	12	8
	B	29	22	7
$P = .027$	C	53	37	16
	D	28	19	9
Circumference of the thorax at nipples	A	43	32	11
	B	43	25	18
	C	29	21	8
$P = .000$	D	10	7	3
Biacromial diameter	A	40	29	11
	B	60	42	18
$P = .000$	C	20	12	8
	D	10	7	3
Bicristal diameter	A	36	26	10
	B	55	38	17
$P = .000$	C	29	20	9
	D	10	6	4
Length of humerus	A	22	15	7
	B	47	33	14
$P = .60$	C	41	27	14
	D	16	12	4
Length of radius	A	27	17	10
	B	53	41	12
$P = .036$	C	33	23	10
	D	13	6	7
Length of palm	A	19	11	8
	B	48	33	15
$P = .41$	C	49	35	14
	D	10	7	3
Breadth of palm	A	27	21	6
	B	50	37	13
$P = .019$	C	42	25	17
	D	9	5	4
Length of middle finger	A	16	9	7
	B	41	31	10
$P = .33$	C	50	35	15
	D	17	11	6
Length of hand	A	24	15	9
	B	51	38	13
$P = .071$	C	41	28	13
	D	12	8	4
Length of lower extremity	A	24	15	9
	B	48	39	9
$P = .33$	C	34	19	15
	D	17	12	5
Length of thigh	A	24	15	9
	B	46	32	14
$P = .57$	C	40	27	13
	D	16	12	4
Length of tibia	A	24	14	10
	B	55	41	14
$P = .046$	C	32	23	9
	D	16	9	7
Length of foot	A	31	21	10
	B	41	27	14
$P = .028$	C	40	29	11
	D	12	8	4
Breadth of foot	A	28	21	7
	B	46	34	12
$P = .014$	C	42	25	17
	D	5	3	2

In the body configurational changes just noted infants with eczema deviate from the control group in the same direction as do infants who have received medical supervision from birth (8) but the growth patterns of eczematous and of supervised infants are not identical. Infants with eczema are shorter and weigh less than supervised infants from

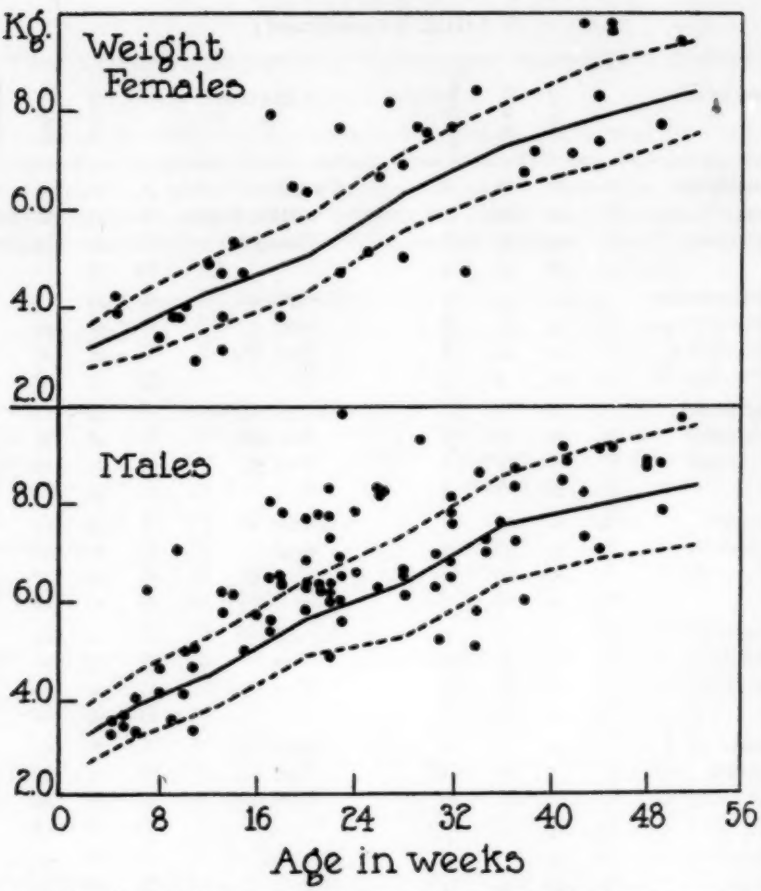

FIG. 1. THE BODY WEIGHT OF INFANTS WITH ECZEMA COMPARED WITH THE CONTROL GROUP

Dots represent infants with eczema. The continuous lines represent the means, and the dotted lines one standard deviation above and below the means for the control infants.

the same social economic environment and their transverse dimensions are smaller with the exception of the diameter of the face which is equally wide in both groups.

The weight-age relationship and eczema in infants

Unsupervised infants with eczema weigh more, on the average, than unsupervised infants without eczema. However, they weigh less, on

the average, than do supervised infants without eczema (Fig. 2). A group of infants, assembled from private practice, shows no striking deviation from the weight curve of non-eczematous supervised infants.

It appears, therefore, that there is a critical level in the weight-age relationship below which infants are relatively immune to eczema. A

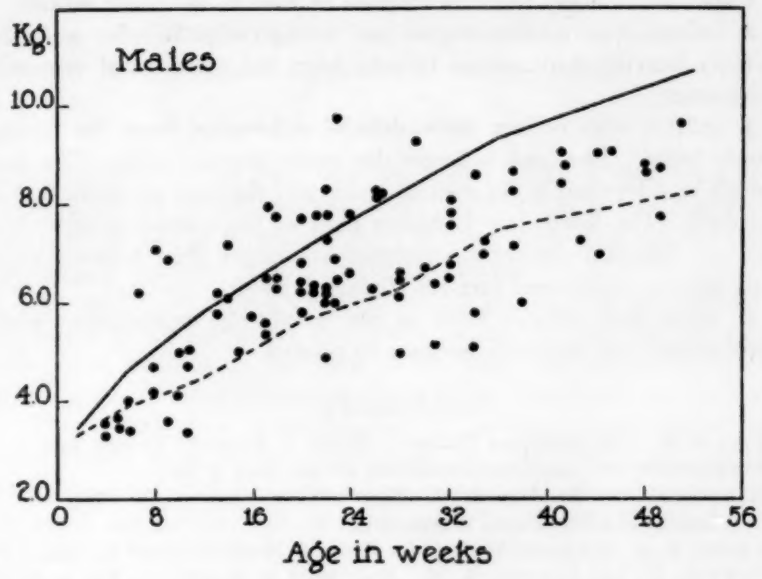

FIG. 2. THE WEIGHT OF MALE INFANTS WITH ECZEMA COMPARED WITH A SUPERVISED GROUP (CONTINUOUS LINE) AND THE CONTROL GROUP (DOTTED LINE)

somewhat similar, though inverted, relationship obtains in the case of acute intoxication. Here, there appears to be a critical weight-age level above which infants are relatively immune to this condition.

Since eczema occurs mainly in infants with body weights above the critical level, and since a higher proportion of supervised infants are above this level than unsupervised infants, one would expect a greater percentage of cases of eczema in private than in clinic practice. The smaller proportion of breast-fed infants in private practice should also favor its greater frequency (9). There are no available data on this point.

The large majority of infants with typical facial eczema are allergic to various foods. It is interesting to speculate on the behavior of

potentially allergic infants who remain below the critical weight level necessary for the development of eczema. Do they remain healthy, or do they develop manifestations which have hitherto not been identified as allergic?

SUMMARY

1. Eczema is about twice as common in male as in female infants.

2. Infants with eczema are, on the average, slightly taller and considerably heavier than control infants from the same social economic environment.

3. Infants with eczema show definite differences from the normal in body build. The head is larger due to its greater width. The face is much broader than in the control group and the eyes are more widely separated. The lower jaw is higher than in the control group. The shoulder, hips and chest circumference are larger than in the control group and the hands and feet are slightly broader.

4. There is a critical level in the weight-age relationship below which infants are relatively immune to eczema.

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AN ANTHROPOMETRIC STUDY OF THE UPPER EXTREMITIES OF CHILDREN

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INTRODUCTION

SEVERAL years ago the author noted a difference in the size of his own two hands. From this observation and an interest in speech, there evolved a study of the relation of the relative size of the two hands to speech and laterality (1937, 1938). In stating the thesis, it was necessary to assume that the difference in the size of the two hands was due to development through use. In a preliminary statement of the study, the author (1935) proposed to determine whether differences in size occur pre- or post-natally.

This question has been answered in part by Schultz (1926) who, from a study of 623 normal well-preserved human embryos, both white and Negro, found that in fetuses, as in adults, the humerus is longer on the right side in over half of the cases. This report includes findings for just one length measurement and would hardly answer completely the question regarding the presence of pre-natal structural asymmetry in the upper extremities.

Thinking it advisable to investigate other characteristics, the length of the arm, the forearm, and the forearm and hand, the width of the bones of the distal end of the ulna and radius, and palm breadth were measured. When these data were obtained, a study was made of the frequency of differences in favor of the right, left or either side. Ninety-three children between the ages of one and eight were measured. For purposes of comparison, these subjects were divided into two age groups, one to four years and five to eight years.

Experimental procedure

Measurements were taken in a well-lighted room at a table of the child's sitting height. Measurements of the forearm and hand, the distal ulna-radius breadth, and the palm were taken with the child seated

at the table. The child faced right while measurements on the left upper extremity were being made and left while measurements on the right upper extremity were being made. The arm was placed in 90° abduction, the forearm in 90° flexion and the hand completely pronated.

Measurements of the arm and forearm were taken with the child standing in an erect position. The arm was held in close to the side of the body. The forearm was placed across the abdomen, the volar surface of the forearm and hand being held flat against the abdomen and the lower ribs of the opposite side of the body. The arm segment was measured as the distance from the acromioclavicular joint to the dorsal surface of the olecranon.[1] Forearm measurements were taken from the proximal aspect of the olecranon (upper quadrilateral surface) to the extreme edge of the distal extremity of the ulna. These measurements were made with inside calipers; pressure was applied.

Because of difficulty encountered in attempting to locate the point of the carpal marking it was thought advisable to measure the distance from the most proximal aspect of the olecranon to the distal extremity of the third row phalange III. An aluminum brachiometer was used in making the forearm hand determinations. The proximal end of the forearm was placed firmly against the solid end piece. The volar surface of the forearm and hand were flattened against the ruler which served as a base. The moveable attachment near the end away from the elbow was brought to the distal extremity of the third row phalange III and readings recorded.

Measurements of the breadth of the distal end of ulna and radius and palm breadth were taken with the calipers. Minimum pressure was applied at the most medial aspect of the capitulum ulnae and the most lateral aspect of the distal extremity of the radius. Palm breadth was taken from the most lateral surface of the digital extremity of the second metacarpal bone to the most medial surface of the digital extremity of the fifth metacarpal bone (minimum pressure).

Measurements of each dimension were repeated three times, the average serving as the indication of length or breadth. One millimeter was chosen arbitrarily as an indication of difference between measurements of the right and left sides.

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[1] With the forearm placed at right angles to the upper arm the dorsal surface of the olecranon was distal to the distal end of the humerus.

Characteristics of cases

Children at the earliest age obtainable were used in this study. It would have been preferable to have presented results for children who had not yet shown any definite one-sided tendencies. Only a few children were available who met this requirement. The majority of the children had reached the stage of development where hand preferences were being shown.

The study included forty-six males and forty-seven females ranging between the ages of one and eight years. Seven males and four females

TABLE 1

Male and female children divided into age groups of one to four years and five to eight years. The per cent of subjects having a larger right, or larger left, or both equal is shown for each measurement

MEASUREMENT		MALES		FEMALES		BOTH SEXES	
		1-4 Yrs.	5-8 Yrs.	1-4 Yrs.	5-8 Yrs.	1-4 Yrs.	5-8 Yrs.
		(21)	(25)	(14)	(33)	(35)	(58)
Arm	R > L	52.4	52.0	7.1	57.6	34.3	55.2
	R = L	9.5	8.0	7.1	21.2	8.6	15.5
	R < L	38.1	40.0	85.8	21.2	57.1	29.3
Forearm	R > L	33.3	56.0	42.9	57.6	34.3	56.9
	R = L	19.0	4.0	14.2	15.2	17.1	10.3
	R < L	47.7	40.0	42.9	27.2	48.5	32.8
Forearm and hand	R > L	28.6	32.0	21.4	46.9	25.7	40.3
	R = L	19.0	8.0	21.4	21.9	20.0	15.8
	R < L	52.4	60.0	57.1	31.2	54.3	43.9
Ulna-radius breadth	R > L	42.8	12.0	21.4	30.0	34.3	22.4
	R = L	28.6	24.0	35.7	33.3	31.4	29.3
	R < L	28.6	64.0	42.9	36.4	34.3	48.3
Palm	R > L	28.6	48.0	42.9	63.6	34.3	56.9
	R = L	28.6	36.0	21.4	21.2	25.7	27.6
	R < L	42.8	16.0	35.7	15.2	40.0	15.5

were included in this series for whom no statement[2] of handedness was obtained.[3] There were thirty-one right-handed males and thirty-eight right-handed females. Three males and three females used both the right and the left hand. Five males and two females were left-handed.

Percentage findings[4]

In Table 1 the ninety-three male and female children are divided into age groups of one to four years and five to eight years.[5] The per cent of subjects having measurements larger on the right side, larger on the left side, or with both equal is shown for each measurement. With the exception of findings for the distal ulna-radius breadth there was a pronounced increase in the per cent of children showing measurements greater on the right side of the body in the five- to eight-year group over the one- to four-year group. In all measurements excepting the ulna-radius breadth the per cent of children showing measurements to be greater on the left was higher in the one- to four-year group in all measurements. The per cent of children with measurements on the right and left sides equal remained approximately the same for all measurements.

The per cent of children having a larger right ulna-radius breadth, a larger left, or both equal was about equal in the one- to four-year group. In the five- to eight-year group, a much larger per cent of the group had a larger left ulna-radius breadth.

It is interesting that the per cent of children having a longer right arm increased from 34.3 per cent for the younger group to 55.2 per cent for the older group. The per cent of children in the younger group having a longer left arm was 57.1 while the per cent for the older group was 29.3.

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[2] The matron's or teacher's statement of the child's handedness served as an indication of handedness. Their knowledge of the child's handedness was usually gained from observations of hand usage.

[3] These children were too young to show any definite unilateral tendencies.

[4] Measurements obtained for each child have been retained by the author. They will be presented in a future paper after a greater number of cases have been studied.

[5] Absolute and percentage frequencies for males and females are presented separately in Table 1. After a greater number of children have been studied it will be interesting to compare tendencies of the two sexes.

TABLE 2

Absolute and percentage frequencies of ninety-three children, studied anthropometrically, showing measurements to be greater on the right side of the body, greater on the left side, or equal on both sides

		MALES (46)		FEMALES (47)		BOTH SEXES (93)	
		Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
Arm	R > L	24	52.2	20	42.6	44	47.3
	R = L	4	8.7	8	17.0	12	12.9
	R < L	18	39.1	19	40.4	37	39.8
Forearm	R > L	21	45.7	25	53.2	46	49.5
	R = L	5	10.9	7	14.9	12	12.9
	R < L	20	43.4	15	31.9	35	37.6
Forearm and hand	R > L	14	30.4	18	39.1	32	34.8
	R = L	6	13.1	10	21.8	16	17.4
	R < L	26	56.5	18	39.1	44	47.8
Ulna-radius breadth	R > L	12	26.1	13	27.7	25	26.9
	R = L	12	26.1	16	34.0	28	30.1
	R < L	22	47.8	18	38.3	40	43.0
Palm	R > L	18	39.1	27	57.4	45	48.4
	R = L	15	32.6	10	21.3	25	26.9
	R < L	13	28.3	10	21.3	23	24.7

Absolute and percentage frequencies for all of the children, males, females and both sexes combined, have been presented in Table 2. Because of differences in age and handedness, there is little that can be gained from consideration of these data. It is interesting, however, that there should be a larger percentage of females showing both sides equal in all measurements excepting the palm than is shown for the males.

Comparison of the two age groups indicates that in the older group there is a larger per cent of subjects showing measurements to be greater on the right side. This might indicate that with increase in age there is a tendency for the right upper extremity to become larger than the left. It is interesting to compare results obtained on children with measurements of the adults.

Absolute and percentage frequencies of right-handed male children (ages one to eight years) and right-handed adult males (college age) showing measurements of the arm, forearm, ulna-radius breadth, and palm breadth to be greater on the right side of the body, greater on the left side, or equal on both sides are presented in Table 3. In all measurements excepting the arm, there was a higher per cent of adults showing measurements on the right side of the body to be greater. In all measurements there was a higher per cent of children than adults showing measurements on the left side of the body to be greater.

TABLE 3

Absolute and percentage frequencies of right-handed male children (ages one to eight years) and right-handed adult males (college age) showing measurements to be greater on the right side of the body, greater on the left side, or equal on both sides

MEASUREMENT		CHILDREN		ADULTS	
		Number	*Per cent*	*Number*	*Per cent*
Arm	R > L	18	58.1	38	50.7
	R = L	2	6.4	11	14.7
	R < L	11	35.5	26	34.6
Forearm	R > L	14	45.2	43	56.6
	R = L	3	9.7	15	19.7
	R < L	14	45.2	18	23.7
Ulna-radius	R > L	9	29.0	51	66.2
	R = L	8	25.8	16	20.8
	R < L	14	45.2	10	13.0
Palm breadth	R > L	15	48.4	53	68.8
	R = L	10	32.3	10	13.0
	R < L	6	19.3	14	18.2

The per cent of right-handed children having a longer arm was greater than the per cent of right-handed adults having a longer arm.

One would more or less expect that if differences in size are due to usage and that in this usage if the soft parts were most affected, palm breadth would show a more noticeable increase in size toward the used side than would the other measurements. There is a very noticeable in-

crease in the percentage of older children having a larger right palm breadth over the younger children. There is also a marked increase in the number of right-handed adults having greater right palm breadth. These same findings hold for measurements of the forearm.

During the measurements, the experimenter observed that in the children of the younger age group there appeared to be a much larger percentage of soft tissue over the distal extremity of the ulna and radius than there was in the older children and adults. This might account somewhat for the finding that the per cent having a larger right, a larger left, or both equal is about the same.

SUMMARY AND CONCLUSIONS

When both sexes are combined, findings on this group indicate that children from the ages of five to eight years tend more frequently to have longer right arms, forearms, forearms and hands, and wider right palms than do children from one to four years of age. Children from the ages of one to four years tend more frequently to have longer left arms, forearms, forearms and hands, and wider left palms than do children from five to eight years of age.

A comparison of right-handed children from one to eight years of age with right-handed adults of college age revealed that the forearm length, distal ulna-radius breadth, and palm breadth were greater on the right side of the body than on the left more frequently for the adult group than for children. For the children the right arm was longer with greater frequency than it was in the adult group. These parts were larger on the left with greater frequency in the children studied than they were in the adult group.

The findings seem to indicate that with increasing age, the upper right extremity is more frequently larger than it is earlier. It seems probable that this tendency toward a greater right might be due, in part at least, to development through use. There is high probability, however, that the tendency toward a greater right might attend the normal growth process and that this structural asymmetry might be attributed to heredity.

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NOTES

THE QUARTILE ABSCISSA OF THE NORMAL CURVE TO 15 PLACES OF DECIMALS[1]

IN THE expression for a probable error there enters always a constant numerical factor, usually stated as 0.6745 or 0.67449. This is, of course, the abscissa of the quartile of the curve, since by definition a probable error divides the area of the distribution into two halves, an inner central half, and two outer quarters, which summed equal the central area.

In computing certain tables in the Department of Biology it became necessary to know the value of the quartile abscissa to a much higher number of decimal places than are given in any tabled value we were able to find. Pearson's Tables[2] give (p. 143) the value of 0.6744897943, but as will presently be shown, this is grossly erroneous in the 8th and subsequent figures. Glover's Tables[3] put (p. 490) the value at 0.6744897500, which is correct *up to* the 10th place, but in error in the last figure.

At the suggestion of Dr. Raymond Pearl the value has been computed to 15 places of figures. The purpose of this paper is to give an account of the methods used and the result attained.

Making the substitution $x = \frac{t}{\sqrt{2}}$ in the equation

$$\frac{1}{\sqrt{\pi}} \int_0^x e^{-x^2} dx = \frac{1}{\sqrt{\pi}} \left[x - \frac{x^3}{3 \times 1} + \frac{x^5}{5 \times 2!} - \frac{x^7}{7 \times 3!} + \cdots \right]$$

[1] From the Department of Biology of the School of Hygiene and Public Health, Johns Hopkins University.

[2] Pearson, K. [Editor]. Tables for Statisticians and Biometricians. Third Edit., Part I. *London* (Cambridge Univ. Press), 1930.

[3] Glover, J. W. [Editor]. Tables of Applied Mathematics in Finance, Insurance, Statistics. *Ann Arbor* (Geo. Wahr), 1923.

gives

$$\frac{1}{\sqrt{2\pi}}\int_0^t e^{-\frac{t^2}{2}}\,dt = \frac{1}{\sqrt{\pi}}\left[\frac{t}{2^{1/2}} - \frac{t^3}{3\times 2^{3/2}} + \frac{t^5}{5\times 2!\times 2^{5/2}} - \frac{t^7}{7\times 3!\times 2^{7/2}} + \ldots\ldots\ldots\ldots\ldots\right] \qquad \text{(i)}$$

The series on the right of the equality in equation (i) was cut off after the term $\frac{-t^{23}}{23\times 11!\times 2^{23/2}}$ and the result equated to 0.25. The initial limits for the root were taken as 0.6744897 and 0.6744898. The determination of the remaining decimals to be added to 0.6744897 was carried out in two ways. In the first of these 0.25 was subtracted from the expression on the right of equation (i), and the result set equal to zero. Then starting in the eighth decimal place the integers, ranging from zero to 9, were successively substituted, and the equation was evaluated for each of these now eight place values of the constant until a change of sign occurred for a pair of successive substitutions. The smaller value was taken as correct to the eighth place. The following decimals were arrived at in the same manner until a value correct to fifteen decimals was reached.

The second technique was an application of the modified form of Newton's method given by Serret[4] (pp. 342-346). With 0.6744897 and 0.6744898 as the initial limits, applying the Newton formula twice in succession, a value correct to fifteen decimals was obtained.

The value of the constant in both cases turned out to be 0.674,489,750,196,082.

In the proof of Newton's formula it is assumed that one root only lies between the initial limits, in our case 0.6744897 and 0.6744898. The presence of more than one root in this interval could also lead to an incorrect value by the use of the first method. The agreement to 15 places of the two values found indicates that *a* root correct to fifteen places has been found, but in order to decide whether it is the right root we substituted 0.67448,97501,96082 as the upper limit for the probability integral, and then applied Gauss's quadrature formula with $n = 10$. The necessary constants (accurate to 16 decimals) for the formula were

[4] Serret, J. A. Cours d'Algèbre Supérieure. Third Edit. T. I. *Paris* (Gauthier- Villars), 1866.

copied from Moors's[5] Table C (folding plate at back). The Gauss formula was applied separately to each of the three integrals, first between the limits zero and 0.2, secondly between 0.2 and 0.4, and finally between the limits of 0.4 and 0.67448,97501,96082. This was done because it meant a great increase in the accuracy of the quadrature formula, and placed the error from that source so far beyond the fifteenth place as to warrant charging any remaining discrepancy solely to an error in the quartile abscissa. Multiplying the maximum possible error in this abscissa, .00000,00000,00000,5, by the ordinate of the normal probability curve at $x = 0.6745$ gives .00000,00000,00000,16 as the maximum error allowable in the area dimension. The three quadratures indicated above gave as the area of the normal probability curve between the limits zero and 0.674,489,750,196,082 the figure 0.25000,00000,-00000,08 — well within the assigned limits.

JOSEPH F. KISH.

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[5] Moors, B. P. Valeur approximative d'une intégrale définie. *Paris* (Gauthier-Villars), 1905.

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RECENT LITERATURE

USEFUL IN THE STUDY OF HUMAN BIOLOGY

In this department will be noticed the books and reprints which are currently received at the Editorial Office. Publications intended for notice here should be addressed to Dr. Raymond Pearl, Department of Biology, School of Hygiene and Public Health, 1901 East Madison Street, Baltimore, Maryland, U.S.A.

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